The Risk Factors Associated with the Prevalence of Pain and Self-Reported Physician-Diagnosed Osteoarthritis in Great Britain's Olympians

By

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DECLARATION

This is to certify that work submitted in this thesis is the result of original research. It is the work of the author with assistance outlined below. No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification at this, or any other university, or institute of learning. All authors and works to which reference has been made are fully acknowledged.

Christine Bower provided the printed address labels for mailing purposes and arranged for franking of the envelopes to distribute the Olympian questionnaire. Dr Debbie Palmer-Green assisted with writing the study advert and mailing the Olympian questionnaire. Dr Debbie-Palmer Green, Professor Mark Batt and Professor Brigitte Scammell undertook supervision of this research and thesis.

ABBREVIATIONS

ACR	American College of Rheumatology
aOR	Adjusted odds ratio
BMI	Body mass index
BOA	British Olympic Association
BP	Body pain
CI	Confidence interval (95% unless stated otherwise)
EF	Emotional functioning
FMHS	Faculty of Medicine and Health Sciences
GB	Great Britain
GH	General health
ID	Identification number
JSN	Joint space narrowing
K/L	Kellgren and Lawrence
MH	Mental health
MSC	Mental health component summary score
MRI	Magnetic resonance imaging
N	Total number of participants
OR	Odds ratio
OA	Osteoarthritis
PCS	Physical component summary score
PF	Physical functioning
PPI	Patient public involvement
PR	Physical role functioning
QoL	Quality of life
SSL	Secure sockets layer encryption
SF	Social functioning
SF-12	Short Form (12 point) questionnaire
SF-36	Short Form (36 point) questionnaire
SPSS	Statistical Package for the Social Science
VAS	Visual analogue scale
VI	Vitality
WHO	World Health Organisation
2D: 4D	Ring / index finger ratio

ABSTRACT

Background: Affecting approximately one in four adults over the age of 50 years in the UK, knee pain is a leading cause of disability in the elderly and bears a significant economic cost. Despite the plethora of studies that have investigated the factors associated with the onset of knee pain and osteoarthritis (OA) in the sedentary population, relatively little is known about the prevalence and factors associated with musculoskeletal pain and OA in an athletic sporting population.

Objectives: This study aimed to: (1) describe the injury patterns, the prevalence of pain, and OA in Great Britain's (GB) Olympians; (2) determine in GB Olympians aged 40 years and older the risk of pain and OA at three joints - the hip, knee and the lumbar spine; and (3) identify the individual risk factors associated with joint pain and OA in GB Olympians aged 40 years and older.

Methods: This was a cross-sectional study design with an internal nested-case control study. A web-based and / or paper questionnaire was distributed by email and / or post to 2742 GB Olympians living in 30 different countries. The questionnaire was used to collect data on risk factors associated with the onset of pain and OA. The presence of OA was defined by a self-reported physician-diagnosis. Pain was self-reported using a body manikin, and defined as pain in or around the selected joint on most days for at least one month. The most severe limb was selected as the index joint for data analysis, if bilateral. Three

separate models of binary logistic regression were constructed to examine the covariates that were associated with pain at the hip, knee, and the lumbar spine. A further three models were constructed to examine the covariates associated with OA at the aforementioned joints. Covariates were identified for analysis, and those that were associated with pain or OA ($P < 0.25$) were purposefully fitted into a multivariable regression model. The final regression models were constructed by refitting, one at a time, the covariates that had previously been excluded until all of the covariates and interactions that were clinically relevant or significant at traditional levels ($P < 0.05$) were included. Relative risk (RR) was estimated using odds ratio (OR), and confounding factors were adjusted (aOR) using logistic regression. The Faculty of Medicine and Health Sciences Research Ethics Committee at the University of Nottingham approved the study.

Results: The response rate was 26%, with 714 returns achieved between the 22nd of May 2014 and the 31st of January 2015. The questionnaires were returned from GB Olympians living in 15 different countries, including the UK. The age of the GB Olympians recruited ranged from 19 to 97 years, with a mean age of 58.76 $\pm$ 16.79 years. Fifty-seven per cent of those recruited were male (n = 405) and 43% were female (n = 309). The age of male GB Olympians recruited ranged from 22 to 97 years, with a mean age of 63.00 $\pm$ 16.30 years. The age range of female GB Olympians recruited ranged from 19 to 93 years, with a mean age of 53.20 $\pm$ 15.78 years.

A total of 821 significant injuries were reported, resulting in an injury rate of 1150 significant injuries per 1000 registered GB Olympians, with 62% reporting they had sustained at least one significant injury (*n* = 441). Cartilage injuries, joint sprain (injury of joint and / or ligaments), and ligament ruptures were prominent in those with knee pain and knee OA. Intervertebral disc injuries, contusions and joint related injury were common in those with pain and OA at the lumbar spine. Pain was most prevalent at the lumbar spine (32.7%), knee (25.6%), hip (23.0%), and the ankle (14.1%). Osteoarthritis was most prevalent at the knee (14.2%), hip (11.1%), lumbar spine (5.0%), and the ankle (1.3%).

Female gender and older age were significantly associated with lumbar spine OA, and older age and a previous significant hip injury were significantly associated with the prevalence of hip OA. Ageing and body mass index (BMI) (kg/m^2), a previous significant knee injury and early-life (20-29 years) generalised joint hypermobility (GJH) (Beighton $\geq$ 4/9) were found to be significantly associated with the prevalence of knee OA.

The strongest factors associated with knee pain were a prior significant knee injury, early-life (20-29 years) varus knee alignment, competing in weight-bearing loading sports, widespread pain, and a higher body mass index (kg/m^2). Factors associated with hip pain included a previous significant hip injury and competing in weight-bearing loading

sports. A one-unit increase in age and BMI (kg/m^2), and a prior significant lumbar spine injury were significantly associated with lumbar spine pain. A one-unit increase in physical well-being was significantly associated with a lower prevalence of pain at the hip and knee.

Conclusion:

This study found that: 1) injury appeared to be constantly the strongest risk factor for pain at the knee, hip and the lumbar spine, as well as OA at the hip and knee; 2) in GB Olympians aged 40 years and older, the knee was most likely affected by OA, and the lumbar spine by pain; 3) participation in weight-bearing loading sports was associated with hip and knee pain, but not hip and knee OA; and 3) generalised joint hypermobility (Beighton $\geq$ 4/9) appeared to be not a risk factor for injury, and nor was it a risk factor for all joint pain/OA, except OA at the knee joint. Female GB Olympians with early-life GJH were more vulnerable to knee OA than their male counterparts. Future research is needed to help determine whether or not GJH is a risk factor associated with the onset of knee OA in the general population, particularly among females. As one of the few modifiable risk factors, joint injury prevention should be part of the future initiatives to reduce the risk of OA, along with maintaining a healthy body weight.

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I dedicate this work to Honey and Eleanor, who were by my side during the write-up of this thesis.

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1.0 INTRODUCTION

1.1 Definition of Osteoarthritis

Osteoarthritis (OA) is described as a heterogeneous group of conditions that can affect all joint tissues, although the loss of articular cartilage and changes in the subjacent bone often show the most marked changes (Herrero-Beaumont et al. 2009). OA is thus defined not as a single disease entity, but represents a collection of disorders with different underlying pathophysiological mechanisms (Aigner & Mckenna 2002). These disorders are a result of both mechanical and biological stimuli that disturb the normal equilibrium between degradation and synthesis by articular cartilage chondrocytes and extracellular matrix, and subchondral bone (Mollenhauer & Erdmann 2002). OA is now widely viewed as a process of repair in response to insult or injury rather than a disease. The pathological changes associated with OA are as much as a product of the attempted repair as of the primary insult or injury, which contributed to the initiation of the process (Arden & Nevitt 2006).

No single universally agreed definition of OA exists because it can be described in terms of the radiographic and histological changes seen in the joint as well as by symptoms. For the purpose of epidemiological research, OA can be defined according to pathology, radiological findings and clinical symptoms (Zhang & Jordan 2010). According to Pereira et al (2011) the three common standard definitions of OA are radiographic OA, symptomatic OA, and self-reported physician-diagnosed OA. Radiographic

OA is defined by structural changes seen on radiographs or other imaging techniques that are consistent with OA pathology (Chakravarty et al. 2008). Symptomatic OA considers cases when both radiographic and joint symptoms related to pathology (i.e. pain, stiffness and loss of function) are present (Arden & Nevitt 2006). Self-reported OA refers to the presence of physician-diagnosed OA (Cheng et al. 2000).

1.2 Nature of Osteoarthritis

Osteoarthritis is synonymous with osteoarthrosis, degenerative arthritis and degenerative joint disease (Hinton et al. 2002). It can affect any synovial joint, but is most frequently seen in the small joints of the hands, the spine, hips and knees (Arden & Nevitt 2006). It is typically suspected based on the presentation of symptoms of pain, stiffness and reduced joint motion and subsequently diagnosed by radiographic imaging of joints. The precise aetiology of OA is not fully understood but is considered to be multifactorial in origin (Zhang & Jordan 2010). There are treatment guidelines for managing the symptoms of knee OA (NICE 2014) but no disease modifying treatment currently exists. The resultant pain and disability associated with OA make it a leading cause of morbidity worldwide (Woolf & Pfleger 2003).

1.3 Pathology of Osteoarthritis

The osteochondral junction is proposed to be a contributing factor in the pathogenesis and onset of symptoms in OA. The osteochondral junction

consists of deeper non-calcified cartilage, calcified cartilage, the cement line, and the subchondral bone plate (Suri & Walsh 2012). The boundary between the calcified and non-calcified cartilage referred to as the tidemark is breached in the osteoarthritic knee. Fissuring of the articular surface extends through the tidemark into the subchondral plate (Suri & Walsh 2012). Angiogenesis occurs at the osteochondral junction, where blood vessels from the subchondral bone breach the tidemark and invade the calcified and non-calcified cartilage, causing the articular cartilage to lose its ability to remain avascular (Suri & Walsh 2012). Vascularisation is accompanied by the growth of unmyelinated sensory nerves into the synovium, non-calcified cartilage and osteophytes (Ashraf et al. 2011). In the osteoarthritic knee, pain may originate from neural tissues including ligaments, muscle, the joint capsule, the periosteum, articular cartilage, the synovium and osteophytes. The pathogenesis of OA is not fully understood but is characterised by a loss of articular cartilage (Roach 2008), sclerosis (Ashraf et al. 2011), osteophyte formation (Sharma et al. 2006) and increased thickness in the subchondral bone (Li & Aspden 1997).

1.4 Clinical Features of Osteoarthritis

The American College of Rheumatology (ACR) define OA for the hand, hip and knee according to clinical features (excluding inflammatory conditions), or by combining clinical and radiographic features, or laboratory and clinical features (Anderson & Loeser 2010; Altman et al. 1990). Clinical features include pain on most days of the last month, inactivity stiffness

lasting no longer than 30 minutes, crepitus on moving the joint, bony tenderness, limitation of movement, no palpable warmth, bony enlargement with osteophytic lipping or osseous protrusions. Symptomatic individuals are usually greater than 50 years of age (Peat et al. 2006; Altman et al. 1986).

1.5 Imaging of Osteoarthritis

The most common method for imaging OA is through the use of radiographs (Menkes 1991). There are several techniques for describing and grading radiographic features of OA, including the Croft Index (Pereira et al. 2011), the Actual Joint Space Width Method (Neumann et al. 2011), the American College of Rheumatology Criteria (Altman et al. 1986), the Ahlbäck Classification System (Petersson et al. 1997), the Nottingham Logically Derived Line Drawing Atlas (Nagaosa et al. 2000), and the Kellgren-Lawrence (K/L) Scale (Kellgren et al. 1963). The K/L Scale is the most frequently used method for describing and grading OA. It consists of five grades that increase in severity and report on joint space narrowing, osteophytes, sclerosis and deformity of bone contour (see Table 1).

Higher K/L grades ($\geq$ 3) are reported to be stronger predictors of knee pain than lower K/L grades ($\leq$ 2) in OA knee positive individuals (Odding et al. 1998). However, there is no consensus if K/L Grade 1 subjects are classified as cases or controls and the K/L method assumes the progression of OA is uniform but it can vary between joints (Lanyon et al.

1998). Furthermore, the K/L is only for tibiofemoral joint OA and the K/L grades are not equidistant, which makes it difficult to measure disease progression amongst individuals with varying grades of OA at baseline (Hart & Spector 2003). Radiographs also have low sensitivity in detecting early changes in hyaline cartilage (Roemer et al. 2011), which can lead to exclusion of early signs of OA.

Table 1: The Kellgren-Lawrence OA Classification

Grade	Criteria
0	Normal
I	Doubtful narrowing of joint space, possible osteophyte development
II	Definite osteophytes, absent or questionable narrowing of joint space
III	Moderate osteophytes, definite narrowing, some sclerosis, and possible joint deformity
IV	Large osteophytes, marked narrowing, severe sclerosis and joint deformity

(Kellgren et al. 1963).

Criticisms of the K/L method have led others to attempt to describe and grade OA according to individual radiological features such as osteophytes and joint space narrowing (JSN). These methods are problematic because the sensitivity and specificity of individual radiological features of OA can vary. Osteophytes have been shown to be the strongest radiological feature that predicts pain at the knee [OR 2.5; 95% CI, 1.6-3.4] compared to JSN [OR 1.8; 95% CI, 1.3-2.7] (Lanyon et al. 1998). In contrast, Croft et al. (1990) reports that minimal JSN (<1.5mm) is a stronger predictor of pain at the hip than osteophytes. The latter study does not provide an odds ratio

for comparison, and disease prevalence is based on the largest osteophyte. Felson et al. (1997) reports a higher sensitivity with smaller Grade One osteophytes, which may account for a lower sensitivity, observed by Croft et al. (1990) when using osteophytes rather than JSN to predict pain at the hip.

The sensitivity of using osteophytes for describing and grading OA is limited in that osteophytes may occur in older adults despite these individuals being asymptomatic (Lanyon et al. 1998). JSN is unlikely to occur in older asymptomatic adults and is more likely to exclude early cases of radiographic OA because JSN is used to define OA cases using a higher K/L grade of $\geq$ 3 (Bedson & Croft 2008). An alternative approach to reading knee radiographs is to use the logically devised line drawing atlas system. Nagaosa et al. (2000) explains that this system was designed to include only joint space narrowing and osteophyte formation with each feature scored from 0 to 3 to allow comparison with the Osteoarthritis Research Society (OARS) atlas. Different line drawings were developed to accommodate a variation in the shape and direction of osteophytes at the lateral tibial plateau and medial femoral trochlea. Separate line drawings for JSN were produced for men and women because men were found to have a higher mean joint space width. This approach was developed for the use with standing, extended anterior-posterior; flexed skyline radiographs but one or more of these views are often missing in retrospective data, thereby limiting its use.

Other imaging techniques are available to view radiological features of OA. These include diagnostic ultrasound, magnetic resonance imaging (MRI) and enhanced contrasted MRI (Möller et al. 2008). Neither ultrasound nor MRI is commonly used within research or clinical practice because radiographs are more cost-efficient and generally more widely available (Kinds et al. 2011). Magnetic resonance imaging is advantageous because it can provide an interpretation of other pathological features of OA, including bone attrition, bone marrow lesions, subchondral cysts and inflammation of the synovial membrane (Hayashi et al. 2011). Both MRI and contrast studies have the potential to better identify pre-disease and those at risk of developing OA.

Magnetic resonance imaging is considered a relatively valid and sensitive measurement tool for identifying degradation of articular cartilage (Quatman et al. 2011). Studies using enhanced-contrast MRI are able to interpret pathological changes in hyaline cartilage in greater detail than radiographs, which can view the attrition of hyaline cartilage only indirectly through JSN (Kinds et al. 2011). Magnetic resonance imaging and contrast studies have the potential to better identify pre-disease and thus those at risk of developing OA. Magnetic resonance imaging has helped develop our understanding of OA pathology by illustrating a correlation between radiographic OA and inflammation of the synovial membrane (Roemer et al. 2010) and a relationship between knee pain and synovitis in OA positive cases (Roemer et al. 2010; Baker et al. 2010).

Diagnostic musculoskeletal ultrasound is a relatively new method for imaging joint OA and it has traditionally been used in the evaluation of tendon pathology (Lento & Primack 2008). The advantages of ultrasound are that it is estimated to be less expensive than MRI (Jacobson 2002), considered safe with no radiation hazard, it is non-invasive, and is widely available (Hayashi et al. 2011; Lento & Primack 2008). It enables visualization of effusion, synovitis, and soft tissue structures like the menisci and articular cartilage, which are known to be involved in the pathophysiology of OA (Abraham et al. 2011). The disadvantages of ultrasound are that it lacks construct and criterion validity and is unable to access inner joint structures to fully visualize hyaline cartilage (Keen et al. 2009).

1.6 Prevalence of Osteoarthritis

Osteoarthritis is thought to be the most prevalent musculoskeletal disorder (Chakravarty et al. 2008). Approximately 10% of the world's population aged 60 years and older is estimated to have significant clinical symptoms at the hip or knee joints that are attributed to the condition (Woolf & Pfleger 2003). The prevalence of OA is reported to rise with age at all joint sites (Arden & Nevitt 2006). The prevalence of radiographic knee OA in adults aged ≥ 45 was 19.2% among the subjects in the Framingham Study and 27.8% in the Johnston County Osteoarthritis Project (Lawrence et al. 2008). These figures are likely to be even higher when one considers that individuals often do not consult medical opinion in the earlier stages of the

condition and that radiographs are too insensitive to identify those with subclinical disease (Nevitt et al. 2008).

Few studies have reported data on the prevalence of radiographic and symptomatic hip OA. Among 978 subjects, aged ≥ 50 years, recruited from the Framingham Study Community cohort between 2002 and 2005, the prevalence of radiographic hip OA (95% CI) was 14.6% (11.1-18.1%), 16.6% (12.6-20.6%), 25.9% (19.8-32.0%), and 31.5% (19.1-43.9%) in those aged 50-59 (*n* = 390), 60-69 (*n* = 337), 70-79 (*n* = 197), and ≥ 80 (*n* = 54). The prevalence of symptomatic hip OA (95% CI) was 3.4% (1.8-5.8%), 2.7% (1.3-5.1%), 6.3% (3.3-10.7%), and 7.4% (0.2%-17.9%) in those aged 50-59, 60-69, 70-79, and ≥ 80. The age-standardised prevalence of radiographic hip OA was 19.6% and symptomatic hip OA was 4.2% (Kim et al. 2014).

In one of few prevalence studies of radiographic midfoot and forefoot OA, the Zoetermeer survey (Van Saase et al. 1989) assessed the prevalence of foot OA (K/L ≥ 2) in a population (n = 6,585), aged ≥ 19 years, living in the Netherlands. The results indicated an overall OA prevalence rate in females of 0.7% (20-24 years) and 10.4% (≥ 80 years). For proximal interphalangeal joints, the prevalence rate in men was between 0.3% (20-24 years) and 18.5% (≥ 80 years). For the 2^{nd}-4^{th} metatarsophalangeal joints, the prevalence in females ranged between 2% (20-24 years) and 24.7% (≥80 years).

In a separate study, the prevalence of OA was recorded in the right foot among 205 participants (71 male; 134 female), aged 62-94 years, recruited from a retirement village (n = 93) and a university health science clinic (n = 112). The results indicated a prevalence of OA of 49.8% at the 1st metatarsophalangeal joint, 22.9% at the 1st cuneo-metatarsal joint, 65.4% at the 2nd cuneo-metatarsal joint, 39.5% at the navicular-first cuneiform joint and 35.6% at the talo-navicular joint (Menz et al. 2010). Thirty-five participants (17.1%) exhibited OA in both the navicular-first cuneiform joint and talo-navicular joint. Future population-based studies are required to understand the risk factors associated with foot OA.

The prevalence of OA is difficult to estimate and varies according to the joint being examined (Thomas 2001) and the characteristics of the study population (Zhang & Jordan 2010). Disease prevalence may also vary according to whether period or point prevalence is used to estimate disease prevalence (O'Reilly et al. 1996), along with the definition used to define OA (Pereira et al. 2011). Disease prevalence has a tendency to be higher when defined by radiographic OA and similar when using a definition of self-reported physician-diagnosed OA and symptomatic OA (Pereira et al. 2011). The proportion of individuals estimated to have symptomatic OA and self-reported physician-diagnosed OA is also higher when incorporating a measurement of period rather than point prevalence (O'Reilly et al. 1996).

The method used to capture and score radiographic images may also influence the prevalence of OA. The prevalence of radiographic knee OA has been shown to be higher when incorporating a lateral view or a skyline view with the antero-posterior (A/P) view (Bedson & Croft 2008; Williams et al. 2004). Radiographic knee OA is also higher when incorporating mild OA changes (K/L $\leq$ 1) with moderate (K/L $\geq$ 2) and severe changes (K/L $\geq$ 3) (Dagenais et al. 2009). Studies imaging both the patellofemoral and tibiofemoral joints have yielded higher disease prevalence than studies imaging only the tibiofemoral joint (Duncan et al. 2007).

The various definitions of pain used to describe symptomatic OA may help to account for the heterogeneity in disease prevalence. The definition of pain varies according to location, type, and duration of symptoms (Bedson & Croft 2008). The location of pain can be defined as 'knee pain' (Odding et al. 1998), 'joint pain' (Lachance et al. 2001), or as 'pain in or around the knee' (Lanyon et al. 1998; O'Reilly et al. 1996). The episode of pain may be defined according to 'current' pain (Odding et al. 1998) or 'ever' having had pain (Cicuttini et al. 1996) or pain 'in the last year' (Davis et al. 1992) or it can be a combination of these definitions (Felson et al. 1997). The duration of pain may also vary according to pain 'lasting more than 15 days' (Cicuttini et al. 1996), 'lasting more than a month' (Lachance et al. 2001), 'lasting one month' (Davis et al. 1992), or 'on most days for one month' (Lethbridge-Cejku et al. 1995).

1.7 Risk Factors for Osteoarthritis

There is evidence to demonstrate that a number of risk factors are associated with OA. The relative importance of these risk factors may vary according to the joint being examined, the different definitions of OA, and the stage of OA (Zhang & Jordan 2010). These risk factors associated with the onset of OA include age, obesity, genetics, muscle strength, bone mineral density, occupational risk, development abnormalities, Heberden's nodes, lower limb malalignment, gender, index-ring finger ratio (2D: 4D), joint laxity and joint injury (Blagojevic et al. 2010; Zhang et al. 2008).

1.7.1 Age

Ageing of the musculoskeletal system is considered to be a factor that contributes to the onset of OA when other risk factors are present, but alone it is not the cause of OA (Anderson & Loeser 2010). The older adult population has been shown to be more susceptible to OA in the hand (Zhang et al. 2002), hip (Dagenais et al. 2009) and knee (Blagojevic et al. 2010). The prevalence of radiographic knee OA (K/L $\geq$ 2) was evaluated in the Framingham Heart Study cohort in 1424 of the 1805 subjects ranging in age from 63-94 years. The prevalence of OA in this study increased from 33% in those aged 60-70 to 43.7% among those aged over 80 years of age ($P < 0.001$) (Felson et al. 1987).

The Johnson County Osteoarthritis Project ($N = 3018$) evaluated the

prevalence of hip and knee OA in a 55-64 year age group and a 75-plus age group (Jordan et al. 2007). The results illustrate that the prevalence of OA when defined either radiographically (K/L $\geq$ 2) or symptomatically are higher in the 75-plus age group. The Chingford Women's Study also found the incidence of radiographic knee OA to be significantly higher in older age females. The incidence of JSN was not significantly higher in the older women (P = 0.77) but osteophytes were (P = 0.003) (Hart et al. 1999). Radiological features such as osteophytes are common in the ageing population and it is possible that this may have led to the overestimation of the incidence of radiographic knee OA in the Chingford Women's Study. In the Framingham study, the prevalence of symptomatic knee OA also increased with age in both males and females (P = 0.003) but this was only significant in female subjects, suggesting that the prevalence of OA may differ between genders (Felson et al. 1987).

1.7.2 Gender

Srikanth et al. (2005) performed a meta-analysis of gender differences in OA and found the prevalence of OA to be lower in males at the knee [Risk Ratio (RR) 0.63; 95% CI, 0.53-0.75] and hand [RR 0.81; 95% CI, 0.73-0.90]. The incidence of OA was also significantly lower in males at the knee joint [Incidence Rate Ratio (IRR) 0.55; 95% CI, 0.32-0.94] and hip joint [IRR 0.64; 95% CI, 0.48-0.86]. However, males under 55 years of age had a greater prevalence of cervical spine OA [RR 1.29; 95% CI, 1.18-1.41]. Females over 55 years of age tended to have more severe knee OA,

which is suggested to be linked to the time of the menopause and decreasing levels of oestrogen. This has created interest in the use of hormone replacement therapy (HRT) in OA. Wluka et al. (2001) demonstrated that the use of HRT is associated with greater cartilage volume in women with no knee pain than women who have lower levels of oestrogen. Maleki-Fischbach & Jordan (2010) explain that it remains unclear whether females have an accelerated rate of cartilage loss around the time of menopause or whether this occurs from early childhood.

1.7.3 Index / Ring Finger Ratio (2D: 4D)

The 2D: 4D ratio refers to the length of the index finger (2^{nd} digit) and the ring finger (4^{th} digit). There are three types of finger patterning that concern whether the index finger is longer (type I), equal to (type II), or shorter than the ring finger (type III). Males tend to have shorter index fingers relative to the ring finger than females (Robertson et al. 2008; Manning 2002) and, on average, males display a lower 2D: 4D ratio than females (Voracek et al. 2010). Individuals with male patterning (i.e. type III - index finger shorter than ring finger) are reported to be almost two-times more likely to have knee OA [aOR 1.94; 95% CI, 1.54-2.44] than those with a different finger patterning. In addition, females with type III finger pattern were also shown to be at a greater risk of knee OA [OR 3.05; 95% CI, 2.08-4.47] than males [OR 1.45; 95% CI, 1.08-1.95] (W Zhang et al. 2008).

Previous studies have shown no association between the index ring finger

ratio and hip OA. Hussain et al. (2014) assessed hand photographs from a total of 14 511 participants in the Melbourne Collaborative Cohort Study. The results indicated type III finger patterning is associated with an increased risk of severe knee OA requiring total knee replacement, but not the risk of severe hip OA. Sigurjonsdottir et al (2013) confirmed type III finger patterning was associated with total knee replacements but not total hip replacements by visually inspecting 5170 hand photographs (2975 females, 2195 males) in the Reykjavik study.

It is unclear what mechanism is responsible for the association between 2D: 4D and knee OA but one theory has suggested that it may be linked to exposure to higher levels of testosterone during intra-uterine life (Robertson et al. 2008; Manning 2002). Furthermore, a low 2D: 4D ratio has been illustrated to be present in hand OA but it might be a consequence of OA rather than a cause (Haugen et al. 2011). A low 2D: 4D ratio has also been shown to be a predictor of sporting ability in females (Paul et al. 2006) and male swimmers (Sudhakar et al. 2013). Currently there is a gap within existing knowledge as to whether the 2D: 4D ratio is a risk factor for the onset of OA in elite level athletes.

1.7.4 Genetics / Heberden's and Bouchard's Nodes

Heberden's nodes are enlargements of the distal interphalangeal joints of the fingers. Nodes at the proximal interphalangeal joints are called Bouchard's nodes. Psoriatic arthritis, hypertrophic pulmonary arthropathy

and diffuse idiopathic skeletal hyperostosis may produce palpable finger nodes similar to Heberden's nodes (Urbano 2001). Heberden's nodes may also occur as a consequence of a traumatic injury to a finger. Heberden's nodes are considered a strong marker for OA of the interphalangeal joints of the hands and their presence is an indicator of generalised OA (Urbano 2001). According to Alexander (1999) there are two types of Heberden's nodes**,** including a lateral node and a central node. The former are considered an immature osteophyte, which is reported to be a stronger predictor of OA than the central node. The latter is considered a traction spur and a marker for extensor tendon contracture.

1.7.5 Obesity

Obesity has been shown to have a strong association with the incidence of radiographic knee OA. In the Baltimore Longitudinal Study of Ageing (Hochberg et al. 1995) a significant association was found between high body mass index (BMI) (> 30kg/m2) and radiographic (K/L $\geq$ 2) knee OA in men [OR 2.40; 95% CI, 1.32-4.35] and women [OR 4.34; 95% CI, 1.89-9.98]. The Bristol OA study found obesity to be the main risk factor for incident radiographic knee OA (K/L $\geq$ 1) [OR 9.1; 95% CI, 2.6-32.2] and progression [OR 2.6; 95% CI, 1.0-6.8] (Cooper et al. 2000). However, Grotle et al (2008) found an association between obesity and radiographic OA of the hand [OR 2.59; 95% CI, 1.08, 6.19] but not the hip [OR 1.11; 95% CI, 0.41, 2.97]. This infers the relationship between obesity and OA is not simply explained by biomechanical overloading.

Sellam and Berenbaum (2013) suggest adipokines secreted by adipose tissue may provide a metabolic link between obesity and OA. Muthuri et al. (2013) conducted a case-control study of Caucasian males and females aged 45 to 86 years from the Genetics of OA and Lifestyle (GOAL) study. This study investigated potential gene-environment interaction between body mass index and each of eight *TGFβ1* polymorphisms in knee and hip OA. The results of the GOAL study illustrated that the *TGFβ1* gene polymorphisms interact with being overweight to influence the risk of large joint OA. Other studies have found evidence of a metabolic inflammatory pathway, with the association between BMI and knee OA explained by higher leptin levels (Karvonen-Gutierrez et al. 2014; Fowler-Brown et al. 2015).

1.7.6 Joint Injury

Joint injury has been shown to be a strong risk factor for the onset of knee OA (Roos et al. 2001) and knee pain (Miranda et al. 2002). Individuals with acute knee injury were found to be at a higher risk of developing knee OA in the Clearwater OA study [OR 7.4; 95% CI, 5.9-9.4] (Wilder et al. 2002), and a nationwide mini-Finland health survey [aOR 4.7; 95% CI, 1.4-15.5] (Toivanen et al. 2010). There is a large disparity between knee injury and the risk of developing knee OA in these two studies. The magnitude of risk may also be underestimated because studies in the literature that examine the effect of injury in OA frequently refer to nonspecific injuries, lack

adequate controls and do not account for exposure to injury.

Muthuri et al. (2011) systematically reviewed the relationship between knee injury and the onset of knee OA in a meta-analysis of observational studies. This study found that a history of knee injury is a major risk factor for the development of knee OA, irrespective of the study design and the definition of knee injury [OR 5.95; 95% CI, 4.57-7.75]. Traumatic joint injury has also been reported to be associated with ankle OA (Valderrabano et al. 2009). Lateral ankle sprains associated with sports (particularly football injuries) were reported to be the main cause of ligamentous injuries of the ankle, which led to the onset of post-traumatic ankle OA (Valderrabano et al. 2006).

1.7.7 Occupational Risk

Previous studies have shown that certain occupational activities that involve excessive and/or abnormal joint loading are associated with an increased risk of OA at the hip (Yoshimura et al. 2000), knee (McWilliams et al. 2011), and the 1st carpometacarpal joint (CMCJ) (Fontana et al. 2007). Hand OA was also reported to be higher among individuals working in occupations that require increased manual dexterity (Hadler et al. 1978). Occupations involving repetitive thumb use were detected to be associated with an increased risk of 1st CMCJ OA in women requiring surgery for 1st CMCJ OA, compared with women with no 1st CMCJ OA (Fontana et al.

2007).

A systematic review by McWilliams et al. (2011) has shown a positive association between knee OA and kneeling [OR 1.30; 95% CI, 1.03-1.63], squatting [OR 1.40; 95% CI, 1.21-1.61], knee bending / straining [OR 1.60; 95% CI, 1.15-2.21] elite sport [OR 1.72; 95% CI, 1.35-2.20] and an overall greater risk with physical occupational activities [OR 1.61; 95% CI, 1.45-1.78]. This explains why certain occupations - such as floor layers [OR 2.7; 95% CI, 1.5-4.6] (Rytter et al. 2008) and miners [OR 1.9; 95% CI, 1.30-2.80] (O'Reilly et al. 2000) - are known to have an increased risk of developing knee pain. In a separate study, the prevalence of OA at the hip was detected to be higher among farmers [OR 9.3; 95% CI, 1.9-44.5], and was associated with prolonged standing and lifting (Croft et al. 1992).

1.7.8 Sport and Physical Activity

The association between sport and physical activity and the risk of developing OA is not fully understood. Sutton et al. (2001) investigated the level of physical activity and risk of self-reported OA and found an increased risk of OA with greater levels of exercise between 20 and 24 years of age (OR 1.6; 95% CI, 0.94-2.73). Other studies have found that recreational exercise and long distance running neither protected against nor increased the risk of knee OA (Chakravarty et al. 2008; Felson et al. 2007; Kettunen et al. 2001). There is evidence that those who undertake

regular physical activity or participate in elite sport are at greater risk of injury (Andersen et al. 2013; Jacobsson et al. 2012; Rechel et al. 2008). This is consequently a risk factor for the onset of knee OA. Tveit et al. (2012) demonstrated that male athletes who participate in contact sports at an elite level have an increased prevalence of OA in the hip [aOR, 2.0; 95% CI, 1.5-2.8] and knee joints following adjustment for age and injury [aOR, 1.6; 95% CI, 1.3-2.1]. Further studies are required to determine the level and frequency of exercise that acts as a risk factor for the onset of hip and knee OA and to ascertain whether this type of exercise is a risk factor for OA at other joint sites and in female subjects.

1.7.9 Malalignment

Previous studies have detected lower limb mal-alignment is associated with the onset and/or progression of OA (Brouwer et al. 2007; Sharma et al. 2001). Leg length inequality of $\geq$ 1 cm has been shown to be associated with an increased onset and progression of radiographic and symptomatic OA in the shorter leg (Harvey et al. 2010). In healthy controls, Sharma et al. (1999) demonstrated that females have greater varus-valgus laxity of the tibiofemoral joint than males, and that anterior posterior laxity does not correlate with age or differ between subjects with knee OA and without knee OA. In those subjects with knee OA, however, varus-valgus laxity increased as joint space decreased.

In a separate study, varus knee alignment was found to be associated with

the development of radiographic OA (K/L $\geq$ 2) at the tibiofemoral joint (Brouwer et al. 2007). The progression of OA (K/L $\geq$ 2) has been shown to be higher in valgus knee alignment compared to neutral alignment at the tibiofemoral joint (Sharma et al. 2001). There is evidence that a sequel of marked laxity in a given joint resulting from varus-valgus alignment or anterior cruciate ligament deficiency is associated with the onset of knee OA, but this is arguably a different entity to hyperextension of the tibiofemoral joint due to hypermobility. A varus tibiotalar joint alignment has also been detected to be associated with the onset of OA at the ankle (Valderrabano et al. 2009; Valderrabano et al. 2006).

1.8 Joint Hypermobility

Early clinical studies imply that with joint hypermobility there is an associated increased prevalence of OA. This relationship is believed to be due to hypermobile joints exerting greater biomechanical stresses on articular cartilage. Alternatively, it may result from genetic encoding of tissue matrix in collagens IX, XI and V (Dolan et al. 2003). Scott et al. (1979) compared 50 females with symptomatic OA involving at least three joints (knees, hips, shoulders, hands, cervical spine and / or lumbar spine) with an age-matched control group and found joint hypermobility (Beighton $\geq$ 4/9) to be significantly higher ($P < 0.05$) in the OA group (24%). Bridges et al. (1992) examined 130 patients (97 females: 33 males) referred to an outpatient rheumatology clinic for musculoskeletal problems or connective tissue disease and found OA in 60% (n = 12/20) of those with joint

hypermobility (Beighton $\geq$ 5/9) compared to 30% (*n* = 33/110) of those without hypermobile joints. Neither of these studies controlled for confounders in the statistical analysis. Both studies are probably subject to attendant selection bias because they are based on current Beighton scores in elderly clinic populations. Hypermobility reduces with age, and biomechanical stresses caused by hypermobility in early-life can only be accounted for by considering historic Beighton scores.

There is evidence that joint hypermobility is associated with OA at the 1st carpometacarpal joint. Jónsson et al. (2009) examined 384 older participants (161 males: 223 females) from the Reykjavik Study and found that those with extension of the 2nd and 5th metacarpophalangeal joint beyond 70 degrees were associated with evidence of radiographic OA at the 1st carpometacarpal joint [OR 3.05; 95% CI, 1.69-5.5). These results are supported by two previous studies by the same lead author (Jónsson et al. 1996; Jonsson & Valtysdottir 1995) but are in contrast to Kraus et al. (2004) who found no effect of high hypermobility on 1st metacarpophalangeal joint OA. Yet Kraus et al. (2004) demonstrated that Beighton scores of $\geq$ 4/9 were shown to have a negative association with OA at the proximal phalangeal joints [OR 0.34; 95% CI, 0.16-0.71]. It is possible that selection bias may have contributed to the different findings because DIP OA was an inclusion criterion by Kraus et al. (2004) whereas Jónsson et al. (2009) recruited participants with an older age range from a community-based population not recruited specifically for OA.

Dolan et al. (2003) examined hypermobility in 716 female subjects under follow-up in the Chingford Study, using a modification of the Contompasis score of $\geq$ 22. Subjects with joint hypermobility were found to have a reduced risk of knee OA (JSN) (OR 0.48; 95% CI, 0.27-0.83) after adjusting for age, height and weight. The procedure used to score the Contompasis scale remains ambiguous and there is no explanation to justify the cut-off threshold of $\geq$ 22 or to assess how reliable this is at defining joint hypermobility. The traditional Beighton $\geq$ 4/9 cut-off threshold yielded only one positive result for joint hypermobility. This is significantly lower than previous estimates and is arguably not representative of the wider population of similar age, gender and ethnicity.

To date, a correlation between joint hypermobility and OA has been shown to be possible. It remains unproven, however, whether joint hypermobility acts as a risk factor for the onset of OA and whether this varies between joints. Future research examining the association between joint hypermobility and OA will need to distinguish between joint hypermobility and joint hypermobility syndrome. Definitional inconsistencies have created confusion among authors in the literature. Some researchers (Azma et al. 2014; Shiari et al. 2012; Sáez-Yuguero et al. 2009; Adib et al. 2005) erroneously refer to ‘joint hypermobility syndrome’ when they are using a method to identify ‘joint hypermobility’: others (Kemp et al. 2010) refer to joint hypermobility when using a method for identifying joint hypermobility

syndrome. The conventional method of classifying joint hypermobility is by using the Beighton 9-point scoring system whereas joint hypermobility syndrome is defined using the Brighton criteria. The Beighton scale is included as a major criterion as part of the Brighton criteria in the assessment of joint hypermobility syndrome (Pacey et al. 2014).

1.8.1 Definition of Joint Hypermobility

The basic definition of a hypermobile joint is described as ”one whose range of motion exceeds the norm for that individual, taking into consideration age, sex and ethnic background” (Grahame 1999, p. 188). The term joint hypermobility is frequently described in the literature as a condition affecting multiple synovial joints (Simmonds & Keer 2007) and less frequently a localized condition affecting a single joint (Juul-Kristensen et al. 2007). Other researchers refer to joint hypermobility as a symptomatic condition responsible for causing musculoskeletal complaints (Azma et al. 2014), yet hypermobile joints are most often found in isolation in otherwise asymptomatic individuals (Hakim & Grahame 2003b).

Researchers in the literature occasionally refer to joint hypermobility using different terminologies that are not always clearly defined. These terms include ‘articular mobility’ (Beighton et al. 1973), ‘articular hypermobility’ (Qvindesland & Jónsson 1999), ‘hyperlaxity’ and ‘hyperextensibility’ (Engelbert et al. 2003), ‘generalised joint hypermobility’ (Scheper et al. 2013) and ‘diffuse joint hypermobility’ (Bridges et al. 1992). Generalised

joint hypermobility is synonymous with diffuse joint hypermobility and is reserved for use when the particular threshold for defining hypermobility is reached. Again, there are inconsistencies between studies on what threshold is adopted to define generalised joint hypermobility, and some researchers (Engelbert et al. 2003) use the term out of context when they are using methods consistent with investigating joint hypermobility syndrome.

The term ‘hyperextensibility’ is used to refer to excessive movement of synovial joints in joint hypermobility and also to skin extensibility in joint hypermobility syndrome. The term hyperextensibility, when used in the context of joint hypermobility, inherently neglects the importance of spinal intervertebral joint flexion that forms part of the conventional Beighton score. The term hyperlaxity is problematic because it implies that joint hypermobility is due to lax ligaments and that ‘accessory’ movement is fundamental in its diagnosis. Yet it is ‘osteokinematic’ movement patterns that are paramount to this diagnosis. The ability to hyperextend the tibiofemoral joint, for instance, is influenced by the connective tissue matrix that forms not only the ligaments but also the joint capsule and the mechanical properties of the surrounding muscle and tendons (Collinge & Simmonds 2009).

1.8.2 Definition of Hypermobility Syndrome

Joint hypermobility was originally considered to represent the upper limits

of normal physiological joint motion (Malfait et al. 2006). Later, it became apparent that an association existed between idiopathic generalised joint hypermobility and musculoskeletal complaints that predisposed the introduction of the 'hypermobility syndrome' (HMS) by Kirk et al. (1967). This was the first comprehensive description in the literature of an association between hypermobility and musculoskeletal symptoms such as pain, joint subluxations and dislocations. Subsequently, it became apparent that HMS is a relatively benign disorder in terms of life-threatening complications and was renamed the 'benign joint hypermobility syndrome' (BJHS). Descriptions of the acronym BJHS make reference to the combination of hypermobility, musculoskeletal complaints as well as Marfan syndrome-like habitus, mild skin features and a greater risk of developing osteoporosis (Hakim & Grahame 2003b).

Clinical signs of mild fragility of connective tissue other than joints, such as blue sclerae, skin hyperextensibility, atrophic scarring or easy bruising became implicated in benign joint hypermobility syndrome. Both joint hypermobility and features of connective tissue fragility are prominent in many heritable disorders of connective tissue including Marfan syndrome, Osteogenesis Imperfect and Ehlers-Danlos syndrome (EDS). As a result, it became increasingly apparent that benign joint hypermobility syndrome is an under-recognized form of a hereditary connective tissue disorder and was renamed the joint hypermobility syndrome (Ferrell et al. 2004). Hereditary connective tissue disorders are diagnosed according to their

genetic disorder rather than joint hypermobility syndrome. Currently, there is no reliable method of differentiating between benign joint hypermobility syndrome and Ehlers-Danlos syndrome (hypermobile type III).

There remains a debate in the literature regarding whether idiopathic generalised joint hypermobility represents the end of the normal spectrum of joint range of motion and joint hypermobility syndrome denotes a polygenic group at the mild end of the spectrum of hereditary connective tissue disorders. There is a need to define clearly idiopathic generalised joint hypermobility based on a tool that more accurately identifies specific genetic causes of the disease. Until then, it is recommended that hypermobility syndrome and benign joint hypermobility syndrome are made redundant and referred to as joint hypermobility syndrome - as defined by the Brighton criteria. In agreement with Tofts et al. (2009), the diagnosis of joint hypermobility syndrome should be applicable to hereditary connective tissue disorders and can be identified by describing joint hypermobility syndrome followed by the tissue diagnosis where applicable.

1.8.3 Identifying Joint Hypermobility and the Hypermobility Syndrome

There are several clinical assessment methods used in the literature to define joint hypermobility including: Carter and Wilkinson, Beighton, the Rotés Quérol method and the Bulbena criteria (see Table 2). In addition, there is a five-part self-report questionnaire for defining joint hypermobility (see Table 3). The recommended clinical assessment method for defining

joint hypermobility syndrome is the Brighton criteria (Table 4)

1.8.3.1 Carter and Wilkinson Criteria

The Carter & Wilkinson (1964) system was introduced to investigate the incidence of persistent generalised joint hypermobility in normal school children (*N* = 81) versus those with congenital dislocation of the hip joint (*N* = 285). Generalised joint hypermobility was diagnosed when more than three of five tests (see Table 2) were positive in both the upper and lower extremities. It was concluded that persistent joint laxity was largely inheritable, and this was deemed an important predisposing factor to congenital dislocation of the hips in schoolboys. It was noted to be less important in schoolgirls, where temporary hormonal changes were proposed to be responsible for joint laxity. Unfortunately, the authors are inexact in their definition of what constitutes a diagnosis of generalised joint hypermobility, and it is unclear whether positive cases are solely reserved for bilateral or unilateral limb involvement. The Carter and Wilkinson (1964) system measures generalised joint hypermobility by incorporating passive extension of the fingers with the radiocarpal joint extended. However, this technique simultaneously assesses the metacarpophalangeal joints (MCPJ), the proximal phalangeal joints and distal phalangeal joints, and is unlikely to be sensitive enough to identify isolated metacarpophalangeal joint hypermobility where there is passive insufficiency in the flexor digitorum superficialis and/or flexor digitorum profundus tendons.

Table 2: Clinical Assessment Methods of Joint Hypermobility

Clinical Assessment Method	Carter & Wilkinson	Beighton & Horan	Rotés Quérol	Beighton et al*	Bulbena Criteria	Contompasis
Passive apposition of the thumb to the flexor aspect of the forearm(s)	✓	✓	✓ (> 185°)	✓	✓ (< 21mm)	✓
Passive hyperextension of the fingers so that they lie parallel with the extensor aspect of the forearm	✓					
Ability to hyperextend the elbow more than 10 degrees	✓	✓	✓	✓	✓ (≥ 10°)	✓
Ability to hyperextend the knee more than 10 degrees	✓	✓	✓ (> 5°)	✓		✓
An excess range of passive dorsiflexion of the ankle and eversion of the foot	✓				✓	✓ Eversion only
Passive extension of the little finger more than 90 degrees with the forearm flat on a table		✓		✓	✓ (≥ 90°)	✓
Passive extension of 2nd finger so that the angle between the distal phalanx and the table is greater than 100 degrees			✓			
Flexion of lumbar spine so that palms of hands rest on floor whilst keeping knees straight		✓	✓	✓		✓
Shoulder external rotation greater than 90 degrees			✓		✓ (> 85°)	
Cervical rotation greater than 90 degrees and cervical side flexion greater than 50 degrees			✓			

Table 2 Cont.

Clinical Assessment Method	Carter & Wilkinson	Beighton & Horan	Rotés Quérol	Beighton et al*	Bulbena Criteria	Contompasis
Passive hip abduction greater than 90 degrees			✓ (Bilateral)		✓ (> 85°)	
Dorsal flexion in metatarsophalangeal joint greater than 90 degrees			✓			
Lumbar lateral flexion with head and column below the horizontal plane			✓			
Holding the proximal end of the tibia with one hand, moving the rotula well to the sides with the other hand					✓	
Dorsiflexion of the toe over the diaphysis of the 1st metatarsal is $\geq$ 90°					✓	
Knee flexion allowing the heel to make contact with the buttock					✓	
Ecchymosis after minimal traumatism					✓	

** Paired test: 1 point for each positive test for each limb. Refer to Appendix A for Contompasis scoring system*

1.8.3.2 Beighton and Horan Criteria

Beighton and Horan (1969) subsequently revised the Carter and Wilkinson (1964) system for their work on joint laxity in patients (*N* = 100) with Ehlers-Danlos syndrome (EDS). The system was modified by replacing passive hyperextension of the metacarpophalangeal joints with extension of the fifth metacarpophalangeal joint beyond 90 degrees with the forearm pronated and resting on a table. Dorsiflexion of the talocrural joint was also replaced with forward flexion of the lumbar spine to determine if the palms of the hands could easily rest flat on the floor. Unfortunately, there was no definition or threshold given for defining generalised joint hypermobility. Nor was there any evidence of the reproducibility of the scoring system.

1.8.3.3 Rotès-Quérol Criteria

The Rotès-quérol et al (1972) recommendations include a more comprehensive list of tests to identify joint hypermobility. This method examines the joints included as part of the modified Beighton scoring system, with the addition of the cervical spine, shoulder, hip, metatarsophalangeal joint, and lateral flexion of the lumbar spine. The author recommends a different cut-off threshold for children and adults, and joint hypermobility is graded into the following four categories: Grade I = 0-2, Grade II = 3-5, Grade III = 6-7, and Grade IV = 8-10.

1.8.3.4 Beighton 9-Point Scoring System

The Beighton 9-point scoring system - also referred to as the modified or

revised Beighton score - has gained widespread international acceptance since it was first introduced in an epidemiological survey of bone and joint disorders in an indigenous rural South African community (*N* =1083 adults and children). Nine identical genetically-determined sites used in the Beighton and Horan (1969) system were adopted, but instead of averaging tests one to four for the paired joints (see Table 2) alternatively, one point was awarded for a positive test for each side of the body for the knee, elbow, thumb and little finger. Thus, scores range from 0 to 9, with a higher score representing a wider joint distribution of hypermobility. Currently, there is no universally agreed score to denote a positive test, and cut-off thresholds for defining joint hypermobility vary between studies. Researchers refer to thresholds as low as $\geq$ 2-4/9 (Smith et al. 2005) and as a high as $\geq$ 6/9 (Tobias et al. 2013). The most common threshold used in the literature is $\geq$ 4/9, which is recommended by the British Society of Rheumatology (Remvig et al. 2007). The reliance on such an arbitrary score frequently leads to the erroneous assumption that if the number of hypermobile joints falls below this threshold they should be categorized as insignificant and non-hypermobile.

There are several additional limitations of the Beighton score, including its lack of representation of lower limb mobility. It provides no indication of the severity of joint hypermobility, and associated traits such as flat feet and mild scoliosis are not included. Furthermore, not only do varied cut-off thresholds limit the ability to make cross study comparisons; pauciarticular

hypermobility at joints other than those in the Beighton scale go unnoticed (Grahame 1999). Thus the method does not account for hypermobility at the proximal and distal interphalangeal joints, glenohumeral joint, cervical spine, or joints at the shoulder, hip, patellae, hind and forefeet, 1st to 4th metacarpophalangeal joints, wrist and temporomandibular joint (Hakim & Grahame 2003b; Grahame 1999). There are no specific descriptions of the Beighton assessment manoeuvres and there is no agreement to determine how the scale should be scored to accommodate variations according to race, ethnicity, and age.

1.8.3.5 The Contompasis Scoring System

The Contompasis scoring system (McNerney & Johnston 1979) was developed at the end of the 1970's. The method is based on a maximum score of 72 points and involves criteria which assessed the level of mobility at the same joint sites as the modified Beighton score, with the addition of hind foot eversion. A maximum of six points can be awarded to each of the joints used in the modified Beighton system, and a maximum of eight points can be awarded depending on the degree of hind foot eversion. The Contompasis system is a more comprehensive scoring system than the traditional modified Beighton score, but it is not widely used in research in the clinical setting - possibly because it is less well known and more time consuming to complete.

1.8.3.6 Bulbena Criteria

The first evidence to support the need for different cut-offs for men and women when defining joint hypermobility was provided in a prospective study by Bulbena et al. (1992). This study assessed the validity of different sets of criteria to define symptomatic joint hypermobility by assessing consecutive cases attending the rheumatology outpatient clinic of Hospital del Mar in Barcelona (*n* = 114) and a control group of non-hypermobile rheumatology patients (*n* = 59). They compared scores from the Carter and Wilkinson's system, the modified Beighton score, and the Rotés Quérol method to produce a basic set of criteria which defined symptomatic joint hypermobility. Men were found to require one point less than females (3/4 in men and 4/5 in females based on ten items).

Although the Bulbena criteria offer a broader view of hypermobility by including the shoulder, hip, foot and toes, this system is not used as frequently as the modified Beighton score. The prevalence of symptomatic joint hypermobility may have been underestimated because the authors used a high Beighton score ($\geq$ 5/9) to recruit older-age subjects. A high Beighton score threshold and older age both reduce the number of cases of joint hypermobility. It is possible that controls selected from patients attending a hospital rheumatology department may have distorted the number of individuals presenting with symptomatic joint pain.

1.8.3.7 Five-Part Self-Report Questionnaire for Joint Hypermobility

Due to a reliance on undertaking a physical examination, the methods for identifying joint hypermobility are relatively inefficient for large epidemiological research. A five-part self-report hypermobility questionnaire was designed with this in mind. This questionnaire consists of information from the modified Beighton scoring method and can be used to identify individuals with joint hypermobility with a reported 84 per cent accuracy (Hakim & Grahame 2003a). The instrument was developed by asking new female attendees (*N* = 212) to the hypermobility clinic at two London NHS teaching hospitals, and a random selection of healthy volunteers (*N* = 57) to complete a ten-part questionnaire. Questions were selected from the clinical experience of the second author and were designed to identify musculoskeletal symptoms and both current and past levels of flexibility. Data analysis involved calculating odd ratios for each question, and six were found to be significant. The model of 'best fit' for sensitivity and specificity contained five of these questions (see Table 3).

Table 3: Five-Part Self-Report Questionnaire for Joint Hypermobility

Questions
1. Can you now (or could you ever) place your hands flat on the floor without bending your knees?
2. Can you now (or could you ever) bend your thumb to touch your forearm?
3. As a child, did you amuse your friends by contorting your body into strange shapes OR could you do the splits?
4. As a child or teenager did your shoulder or kneecap dislocate on more than one occasion?
5. Do you consider yourself double-jointed?

Affirmative responses to two or more questions were used to classify subjects as having joint hypermobility.

To assess the reproducibility of this instrument, a second cohort consisting of hypermobile cases with benign joint hypermobility syndrome (*N* = 170) and controls (*N* = 50) were surveyed. Data analysis indicated that a positive answer to any of the two questions in the five-part questionnaire gave the highest combined sensitivity and specificity for detecting joint hypermobility. Sensitivity and specificity was 84% and 89% in the first cohort and reproduced with values of 84% and 80% in the second. The validity of the questionnaire was assessed further in a separate survey of 80 unselected individual twins attending the Twin Research Unit (Hakim et al. 2004). Each patient had undergone a physical examination for joint hypermobility, assessed using the modified Beighton score, and had

completed the questionnaire. Sensitivity and specificity of the questionnaire for joint hypermobility in the twins were reported to be similar to those in the previous study (Hakim & Grahame 2003a) but no figures were actually given. The questionnaire is more efficient in large epidemiological studies compared with the undertaking of a physical examination, but it cannot identify isolated hypermobile joints. The questionnaire also requires further validation in community-based populations.

1.8.3.8 Brighton Criteria

The revised 1998 Brighton criteria is the most widely used instrument for classifying joint hypermobility syndrome, although its use has not yet been validated in children less than 16 years of age (Pacey et al. 2014). The Brighton criteria retain the use of the modified Beighton score for diagnosing hypermobile joints, albeit in a more flexible format (Grahame 2007). Joint hypermobility syndrome may be diagnosed with a current or historic Beighton score $\geq$ 1, 2 or 3/9 or 0/9 in those older than 50 years of age with the proviso that other criteria are sufficiently met (Hakim & Grahame 2003b). The Brighton criteria consist of two major criteria and a set of minor criteria as shown in Table 4.

Joint hypermobility syndrome is diagnosed in the presence of two major criteria, in one major and two minor criteria, or in four minor criteria. Two minor criteria are sufficient where there is a first-degree relative affected by hypermobility (Bird 2007). The Brighton criteria exclude individuals with a

known hereditary disorder of connective tissue from the diagnosis of joint hypermobility syndrome (Tofts et al. 2009). Genetic tests are used to distinguish the latter from other systemic diseases and from identifiable hereditary connective tissue disorders such as Marfan or Ethlers-Danlos syndromes (EDS) other than the EDS hypermobility type (formerly EDS type III), which are defined by Ghent (De Paepe et al. 1996) and Villefranche criteria (Beighton et al. 1998) respectively.

The reliance on a particular threshold for defining joint hypermobility has led to an erroneous assumption in the literature that hypermobile joints falling below this threshold are insignificant. The Brighton criteria was devised partly with this in mind, and it is prudent to consider that a single symptomatic hypermobile joint is sufficient to satisfy the definition of joint hypermobility syndrome, so long as the other features are evident (Hakim & Grahame 2003b). Currently, those who fall below the threshold for a positive Beighton score and who do not meet the diagnosis of joint hypermobility syndrome are considered negative cases in the literature despite many of these individuals being known to have a single or more hypermobile joints.

Table 4: The Brighton Criteria for Joint Hypermobility

Minor criteria	A Beighton score of 4/9 or greater (either currently or historically)
	Arthralgia for longer than 3 months in 4 or more joints
Major criteria	A Beighton score of 1, 2 or 3/9 (0,1, 2 or 3 if aged 50+)
	Arthralgia (> 3 months) in one to three joints or back pain (> 3 months), spondylosis, spondylolysis / spondylolisthesis
	Dislocation / subluxation in more than one joint, or in one joint on more than one occasion
	Soft tissue rheumatism > 3 lesions (e.g. epicondylitis, tenosynovitis, bursitis)
	Marfanoid habitus (tall, slim, span/height/ratio > 1.03, upper: lower segment ratio <0.89, anarchnodactyly (positive Steinberg/wrist signs)
	Abnormal skin: striae, hyperextensibility, thin skin, papyraceous scarring
	Eye signs: drooping eyelids or myopia or antimongoloid slant
	Varicose veins or hernia or uterine/rectal prolapse

Criteria Major 1 and Minor 1 are mutually exclusive as are Major 2 and Minor 2 (Bird 2007).

1.8.4 Pathophysiology of Joint Hypermobility

The pathophysiology of joint hypermobility cited in the reviewed literature (Collinge & Simmonds 2009; Simmonds & Keer 2007; Russek 1999) is attributed to an imbalance in the ratio of type III to type I collagen based on an editorial review by Child (1986). This review reports the results of a separate study investigating the role of inherited collagen deficiency in 72 patients attending the rheumatology clinic at a London NHS Teaching Hospital. Twenty-two female patients with joint hypermobility were reported to have undergone forearm skin biopsy for collagen synthesis type analysis, and 15 of these also for electron microscopy. In the review, skin biopsies were reported to have revealed a significant increase in the ratio of type III to type I collagen in 14 of the 22 patients, but collagen ratios were reported in only ten patients in the original referenced study (Handler et al. 1985). A higher ratio of the elastic type III collagen in the tissue matrix is proposed to reduce tissue stiffness and lead to joint hypermobility. However, biopsies in the aforementioned referenced study were taken only from the skin in the forearm and do not sufficiently substantiate proof of a correlation of higher levels of type III collagen in periarticular joint structures believed to be responsible for joint hypermobility.

Elevated levels of insulin-like growth factor-1 (IGF-1), insulin and growth hormone (GH) have been discovered in patients with hypermobility syndrome (HMS) (Denko & Boja 2001). Female patients (n = 24) were found to have statistically higher serum levels of GH, IGF-1 and insulin

than age-matched and gender-matched controls. Males (*n* = 7) also had significantly higher elevated serum levels of GH and insulin compared to controls whereas serum IGF-1 levels - despite being higher in HMS patients - did not reach significance, possibly due to a small sample size. Patients were diagnosed with HMS based on common features of the Hospital del Mar (Barcelona) criteria (Bulbena et al. 1992), yet less than half of the Hospital del Mar criteria were included. There was no explanation to justify the use of 13 additional indicators that were used to diagnose HMS. Unfortunately, the authors failed to use any of three recognised methods – such as the Carter and Wilkinson system, Beighton or Rote's criteria of diagnosing joint hypermobility per se. Although a number of the systemic criteria included in this study are features known to be associated with joint hypermobility syndrome, they are not included in the diagnosis of joint hypermobility syndrome as defined by the Brighton criteria.

The weight of evidence now suggests that joint hypermobility in the clinical setting is a mild form of an underlying hereditary disorder of connective tissue, indistinguishable from, and possibly identical to, the hypermobility type EDS (HT-EDS) (Grahame 2007). It remains unclear whether joint hypermobility in the community population is genetically determined or whether it represents the extreme end of a spectrum of normal joint range of motion (Hakim & Grahame 2003b). Studies investigating the genetic encoding of tissue matrix in joint hypermobility may help us to understand

the underlying mechanisms of joint hypermobility but these types of study are rare. Since joint hypermobility is a feature of many hereditary disorders of connective tissue such as Osteogenesis Imperfecta (OI), Marfan and Ehlers-Danlos syndromes (EDS), it is the latter that have provided valuable insights into pathophysiology of joint hypermobility. Mutations in genes encoding fibrillar collagens or collagen-modifying enzymes have been recognized for OI and the classic form of EDS. Yet mutations in the different types of collagen involved in hypermobility type Ehlers-Danlos syndrome (HT-EDS) and the related phenotype joint hypermobility syndrome remain largely obscure (Malfait et al. 2006; Zweers et al. 2004).

Although mutations in COL3A1 often result in the severe and life-threatening vascular type of EDS, one family was described with a mutation in COL3A1 without obvious vascular compromise that resulted in a phenotype reminiscent of HT-EDS (Narcisi et al. 1994). To date, there are no further cases reported within the literature of COL3A1 associated with HT-EDS, and the previous case may be explained by a late onset of vascular symptoms in this family (Zweers et al. 2003). Mutations in genes encoding fibrillar collagens type I (COL1A1 and COLIA2) have been recognized in OI and are shown to play an important role in joint hypermobility. Mutations in the collagen type V genes can also be identified in half the patients with the classic type of EDS. In approximately one third of these patients, the classic type of EDS is caused by mutations leading to a non-functional COL5A1 allele resulting in haploinsufficiency of

type V collagen. In a small proportion, structural mutation in COL5A1 and COL5A2 results in defective type V collagen protein (Malfait et al. 2006). During fibrillogenesis, type V collagen is understood to interact with type I collagen, and when disrupted this can result in fibrils that are disrupted in shape and diameter (Hausser & Anton-Lamprecht 1994).

Complete and partial deficiency of tenascin-X (TNX) results in two distinctly different connective tissue disorders (Zweers et al. 2004). Complete deficiency of the extracellular-matrix protein TNX encoded by the TNXB gene has been shown in patients with a phenotype that resembles the classic EDS, with marked joint hypermobility, skin hyperextensibility, and easy bruising (Schalkwijk et al. 2001). The absence of atrophic scars and recessive inheritance distinguishes TNX deficiency from the classic type of EDS (Zweers et al. 2004). Partial deficiency of TNX - also termed haploinsufficiency - is defined as a “situation in which the protein produced by a single copy of an otherwise normal gene is not sufficient to ensure normal function” (Zweers et al. 2004, p. 2745). Nearly half of nine family members with haploinsufficiency of TNX were shown to have generalised joint hypermobility. Skin hyperextensibility and easy bruising, commonly seen in individuals with complete TNX deficiency, were absent in these family members. A number of the family members with haploinsufficiency of TNX had recurring joint subluxations and chronic musculoskeletal pain (Zweers et al. 2003).

Either deficient TNX or decreased expression of TNX may disturb the deposition of collagen and the elastic fibre network, which may increase ligament and tendon laxity in joint hypermobility (Schalkwijk et al. 2001). The majority of cases of joint hypermobility cannot be explained by TNX haploinsufficiency as it was detected in only 5-10% of patients with HT-EDS or joint hypermobility syndrome. Traits associated with TNX deficiency suggest that it results in a new type of EDS rather than the HT-EDS or joint hypermobility syndrome phenotype (Zweers et al. 2004). Furthermore, TNX deficiency is strikingly different in nature and considered a recessive disorder, whereas haploinsufficiency of TNX is presumed to be an autosomal trait (Zweers et al. 2003) and produces clinical features primarily in females in accordance with HT-EDS and joint hypermobility syndrome (Schalkwijk et al. 2001). The identification of the non-collagenous TNX in a subtype of HT-EDS, and joint hypermobility syndrome implies that the search for the cause of joint hypermobility should extend beyond collagens (Zweers et al. 2004).

1.8.5 Prevalence of Joint Hypermobility

The prevalence of joint hypermobility varies in the literature largely due to varying diagnostic criteria and is typically inversely proportional to the cut-off threshold used for defining joint hypermobility on the Beighton score. For instance, in a population of 705 African non-pregnant nulliparous women aged nine to 36 years, the prevalence of joint hypermobility varied from 50.5%, 30.8% and 18.6% according to a modified Beighton score of $\geq$

3/9, ≥ 4/9, and ≥ 5/9 respectively (Verhoeven et al. 1999). Joint hypermobility also tends to be higher using the modified Beighton scoring system compared with the Biro system. The former system accounts for individual joints on both sides of the body whereas the latter considers both sides of the body to be equal. The non-dominant side of the body tends to be more hypermobile (Verhoeven et al. 1999; Rikken-Bultman et al. 1997), and this can lead to the prevalence of joint hypermobility being underestimated when using the Biro system. For example, based on the Biro system ≥ 3/5, 50 out of 658 female Dutch school children (7.6%) were diagnosed with joint hypermobility, but 88 (13.4%) received the same diagnosis based on the modified Beighton score ≥ 4/9 (Rikken-Bultman et al. 1997).

Joint hypermobility is usually highest at birth and diminishes with age during adolescence and adult life (Rikken-Bultman et al. 1997; Larsson et al. 1993). Joint hypermobility is reported in 10.6% of a UK sample of male school children compared to 27.5% in females (Clinch et al. 2011) and 12.9% in a sample of Icelandic male school children compared to 40.9% in females (Qvindesland & Jónsson 1999). 1156 of 6022 children in the Avon Longitudinal Study of parents and children received a diagnosis of joint hypermobility (Beighton ≥ 4/9), with a higher incidence in girls (at 27.5%) than boys (at 10.6%) (Clinch et al. 2011). Joint hypermobility appears to be around three times higher in females than males in the literature reviewed (see Table 5), which is consistent with previous findings of Hakim and

Grahame (2003b). The distribution of joint hypermobility varies between sexes, with over 40% of girls diagnosed with hypermobility at the 5th metacarpophalangeal joint and 15% at the trunk compared with approximately 29% and 1.7% of boys respectively (Clinch et al. 2011). It may therefore be concluded that it is normal to have hypermobility at the 5th metacarpophalangeal joint in female teenagers and trunk hypomobility due to tight hamstrings in male teenagers, which, if correct, would undermine the validity of the modified Beighton scoring system.

The decline in joint hypermobility is more rapid in males than females, irrespective of ethnicity. A study of 792 Maori and European subjects reports that joint hypermobility (Beighton $\geq$ 4/9) in both Maori and European males fell sharply by 20 years of age, compared to a linear decrease in both Maori and European females up until the age of 30 years, at which point it was roughly equal between the sexes (Klemp et al. 2002). A similar trend was reported in a rural population in Nigeria (N = 204) where joint hypermobility (Beighton $\geq$ 4/9) declined faster in males than females up until the third decade of life (Birrell et al. 1994). In two groups of Dutch school children, the prevalence of joint hypermobility (Beighton $\geq$ 4/9) declined with age as expected from 15.4% in group one (n = 252, aged 4 to 13 years) to 13.4% in group two (n = 658, aged 12 to 17 years). Yet the percentage of females diagnosed with this condition in group two (19.1%) was higher than those younger children in group one (18.3%), the figures reflecting a temporary increase in females during adolescence.

Females are known to have a temporary increase in joint flexibility during pregnancy. The hormone relaxin, produced by the ovary and placenta, is believed to help relax ligaments and widens the cervix in preparation for a vaginal delivery and is associated with generalised joint hypermobility. Other studies indicate that despite the increase of joint flexibility during pregnancy it does not correlate well with maternal oestradiol, progesterone, or relaxin levels (Marnach et al. 2003). Joint hypermobility is shown to be more prevalent among those of African or Asian descent compared with Caucasians (Hakim & Grahame 2003b; Birrell et al. 1994) with up to 40% of females in some races affected (Al-Rawi et al. 1985). The prevalence of joint hypermobility is reported to be higher in obese female school children (Clinch et al. 2011), and among musicians and individuals in certain sports. In professional female dancers (*N* = 36) in Amsterdam joint hypermobility (Beighton $\geq$ 4/9) was recorded in 66% (Scheper et al. 2013), in 39.5% (Beighton $\geq$ 5/9) of Australian female netball players *(N* = 200) (Smith et al. 2005), and in 33% of English league professional football players (*N* = 54) (Konopinski et al. 2012). These figures help to illustrate that while hypermobile joints may largely be inheritable they can also be acquired through flexibility training.

The prevalence of joint hypermobility (Beighton $\geq$ 4/9) in the general adult population has previously been reported to be between 10% and 30% (Hakim & Grahame 2003c), 25.4% in male and 38.5% in female university

students in Iraq (Al-Rawi et al. 1985), and 26.5% in Dutch school children (Van Der Giessen et al. 2001). In the literature reviewed (see Table 5), joint hypermobility (Beighton $\geq$ 4/9) was diagnosed in a sample of 28% of Icelandic school children, 14% of Dutch school children, and 19.2% of UK school children. The prevalence of joint hypermobility (Beighton $\geq$ 4/9) in adults ranged from 5 to 15% in adults of mainly European Caucasian background, 30.8 to 43% of adults of African descent and 2.4 to 29.4% of adults from countries in Asia. A number of these studies recruited individuals who were attending hospital departments with unexplained medical conditions (Ishaq et al. 2010) and musculoskeletal complaints or connective tissue disease (Bridges et al. 1992), which may positively skew the prevalence of joint hypermobility due to selection bias. The study by Ishaq et al. (2010) reported the prevalence of joint laxity to be rather high - at 77.1% - by calculating the percentage of individuals with a modified Beighton score of = 4-6/9 (*n* = 54) divided by the sum of those with a Beighton score > 6-9/9 (*n* = 70). The true prevalence of joint laxity in this study defined by Beighton = 4-6/9 should be calculated by dividing the number of positive cases (*n* = 54) by the total sample (*N* = 1000). This provides a prevalence rate of 5.4% (Beighton = 4-6/9) and 1.6% (Beighton > 6/9) respectively.

In summary, joint hypermobility is difficult to estimate because authors use different methods to define the condition. The internationally accepted modified Beighton scoring system does not account for joint hypermobility

variation according to age, gender and ethnicity, and the cut-off threshold often varies between studies. Large populations' studies are required to identify suitable cut-off thresholds on the modified Beighton score; thresholds that are sensitive to age, gender and ethnicity. Joint hypermobility appears to be more prevalent in children, in females and in some ethnic groups, and thus it is likely that a higher cut-off threshold is required in these individuals. The true prevalence of joint hypermobility syndrome is currently unknown, although it is believed to be less common than joint hypermobility (Hakim & Grahame 2003b). The application of the Brighton criteria led to an unexpectedly high prevalence of joint hypermobility syndrome among unselected routine rheumatology outpatient referrals both in Chile (Bravo & Wolff 2006) and in the UK (Grahame & Hakim 2004). In the UK, rheumatologists' estimates of the number of cases seen annually strongly suggest that the true diagnosis in a majority of patients with joint hypermobility syndrome is much greater than previously thought (up to 95%) (Grahame 2007).

Table 5: Prevalence of Joint Hypermobility Reported in the Literature

Population	Criteria used	Age in years	Male (n)	Prevalence of Joint Hypermobility (JH) in males (%)	Female (n)	Prevalence of Joint Hypermobility in females (%)	Total Prevalence (%)	Reference
US adults	Beighton ≥ 5/9	18-83	33	0%	97	15%	15%	Bridges et al. (1992)
British unselected monozygotic (MZ) and dizygotic (DZ) female twins	5-part self-report questionnaire for JH	21-81	N/a	N/a	955	19.5% in MZ (*n* = 483); 22.1% in DZ (*n* = 472)	21%	Hakim et al. (2004)
Maori and European New Zealanders	Beighton ≥ 4/9	5 and older	341	2.2% in Maori (*n* = 4) ; 1.9 % in Europeans (*n* = 3)	451	9.0% in Maori (*n* = 23); 5.6% in Europeans (*n* = 11)	5%	Klemp et al. (2002)
Icelandic children	Beighton ≥ 4/9	12	124	12.9%	143	40.5%	28%	Qvindesland & Jónsson (1999)
African non-pregnant nulliparous women	Beighton score (≥3/9, 4/9, 5/9)	9-36	N/a	N/a	705	50.5% scored ≥ 3 30.8% scored ≥ 4 18.6% scored ≥ 5	30.8% (Beighton > 4)	Verhoeven et al. (1999)*
Iranian soldiers	Beighton ≥ 4/9	17-21	718	29.4%	N/a	N/a	29.4%	Azma et al. (2014)
Dutch school children	Beighton ≥ 4/9	Group 1 = 4-13 Group 2 = 12-17	461	12.9% (group 1); 7.6% (group 2)	449	18.3% (group 1) 19.1% (group 2)	14%	Rikken-Bultman et al. (1997)**
UK school children	Beighton ≥ 4/9 Beighton ≥ 6/9	13.8	2961	10.6% 1.3%	3061	27.5% 7.0%	19.2%	Clinch et al. (2011)

* Also used Biro system but results not reported; ** Biro system results not included

Table 5 Cont.

Population	Criteria used	Age in years	Male (n)	Prevalence of JH in males (%)	Female (n)	Prevalence of JH in females (%)	Total Prevalence (%)	Reference
Nigeria population	Beighton ≥ 4/9	6-66	-	35%	-	57%	43%	Birrell et al. (1994)
Iraq students	Beighton ≥ 4-6/9	20-24	1187	25.4%	587	38.5%	29.8%	Al-Rawi et al. (1985)
English league professional soccer players	Beighton ≥ 4/9	18-27	54	33.3%	N/a	N/a	33.3%	Konopinski et al. (2012)
Australian netball players	Beighton 2-4/9 Beighton ≥ 5/9	6-16	N/a	N/a	200	25.5% 39.5%	39.5%	Smith et al. (2005)
Professional dancers in Amsterdam	Beighton ≥ 4/9	Not provided	N/a	N/a	36	66%	66%	Scheper et al. (2013)
Hospital patients in Karachi, Pakistan	Beighton 4-6/9 Beighton 7-9	14-60	717	75.9% 68.6%	283	24.1% 31.4%	2.4%	Ishaq et al. (2010)
Undergraduate university students in Kuwait	Beighton ≥ 4/9	18-29	204	29.4%	186	14.5%	22.3%	Al-jarallah et al. (2014)
High school students in Ankara, Turkey	Beighton ≥ 4/9	13-19	428	7.2%	433	16.2%	11.7%	Seçkin et al. (2005)

1.8.6 Joint Hypermobility and Musculoskeletal Pain

There appears to be only a limited number of studies that have examined joint hypermobility as a potential risk factor for the onset of musculoskeletal pain. Tobias et al. (2013) measured joint hypermobility in children (Beighton $\geq$ 6/9) from the Avon Longitudinal Study of Parents and Children (*n* = 2901) and found an increased risk of at least moderately troublesome musculoskeletal pain at the shoulder (aOR 1.68; 95% CI, 1.04-2.72), knee (aOR 1.83; 95% CI, 1.10-3.02), and ankle / foot (aOR 1.82; 95% CI, 1.05-3.16) after adjustment for sex, maternal education, and body mass index. Sohrbeck-nøhr et al. (2014) examined children (*n* = 301) within the Copenhagen Hypermobility Longitudinal Study for the Beighton test at either eight or ten years of age and then re-examined each child when they reached 14. Children with joint hypermobility (Beighton $\geq$ 4/9) were found to have a risk three times greater for developing joint pain in adolescence [OR 2.76; 95% CI, 0.81-9.38], but this association was not statistically significant, possibly due to a small sample size. Further research is recommended to determine whether joint hypermobility is a risk factor for musculoskeletal pain in the adult population.

1.8.7 Joint Hypermobility and Injury

Individuals with joint hypermobility are reported, at least in the clinical setting, to be at greater risk of joint dislocations and tendinopathies. It is hypothesized that impaired static and dynamic neuromuscular movement control in those with joint hypermobility also contributes to an increased

risk of injury in sport (Soper et al. 2015). Those with joint hypermobility are reported to be at greater risk of injury in elite professional football (Konopinski et al. 2012), amateur rugby (Stewart & Burden 2004) and junior netball (Smith et al. 2005). Professional dancers with joint hypermobility are reported to be more vulnerable to musculoskeletal and psychological complaints (Scheper et al. 2013). Two further studies in the literature report there is no greater risk of injury in hypermobile individuals in lacrosse (Decoster et al. 1999), or professional football (Collinge & Simmonds 2009). A greater time loss from competition following injury was reported in hypermobile professional dancers (Briggs et al. 2009) and professional football players (Collinge & Simmonds 2009).

The aforementioned studies are subject to a number of methodological limitations, including insufficient statistical power (Scheper et al. 2013; Konopinski et al. 2012), an incorrect sample size calculation (Konopinski et al. 2012), the potential for selection bias resulting from convenience sampling (Smith et al. 2005), and recall bias resulting from study designs being retrospective in nature and reliant upon the self-recall of past injuries (Smith et al. 2005). In addition, none of the studies in the literature have controlled for potential confounders. Comparisons between these studies are impeded by discrepancies in design, methodology and variations in the Beighton score cut-off threshold used to define joint hypermobility. Pacey et al. (2010) conducted a systematic review and used a standard cut-off of Beighton $\geq$ 4/9 to overcome variations in the threshold used to define joint

hypermobility. This review reported an increased risk of knee joint injury for hypermobile participants playing contact sports (OR 4.69; 95% CI, 1.33-16.52). Despite its use of stringent inclusion and exclusion criteria, this review did not account for variations in either the injury definition or the methodology used to record injury epidemiology which ultimately contributed to differences between the results of the studies.

1.09 Injury Definitions in Sport

The different definitions and variations in the methods used in injury surveillance studies in sport have created inconsistencies in reporting data (Fuller et al. 2007). This partly explains why different incidences of injury are found and why it is often difficult to make inter-study comparisons (Van Mechelen et al. 1992). In some studies injuries are defined by 'time-loss' from sporting activities (Orchard & Seward 2002; Hawkins & Fuller 1999). Definitions based on time-loss require the participant to be absent for one day from training, competition or both. Time-loss injuries are influenced by the availability of medical provision, the value of the competition or the selection of the participant, and the type of injury that may cause absence from one sport but not another. Time-loss injuries should be defined according to the participant's ability to return to competition or training, regardless of whether or not such a fixture is due to take place.

Injuries can be defined according to whether the participant experiences performance restriction (Orchard et al. 2005), or the next most common

definition to time-loss, those that require medical attention (Fuller, Molloy, et al. 2007). The International Olympic Committee (IOC) define medical attention injuries or illnesses that result in an athlete receiving medical attention, irrespective of time-loss from competition or training (Junge et al. 2008). Medical attention injuries in elite athletes generally mean attending the team physiotherapist or doctor with no time-loss. However, in other studies a medical attention injury is only reportable when the subject is treated in a 'hospital casualty department' (Maehlum & Daljord 1984). Definitions based on time-loss are susceptible to overlooking less serious and / or overuse injuries and athletes sometimes compete despite an injury. Medical attention (only) definitions are capable of picking up non time-loss injuries.

The international recognition of the benefit of adopting common definitions of injury has led to the publication of consensus statements in sports, such as football (Fuller et al. 2006), rugby (Fuller, Molloy, et al. 2007), athletics (Junge et al. 2008), and cricket (Orchard et al. 2005). Consensus statements in rugby and football define an injury as any physical complaint sustained by a player that results from a match or training, irrespective of the need for medical attention or time-loss from football activities. Any injury that results in a player being unable to take a full part in future training or match play is defined as a 'time-loss' injury, and 2) any injury that results in a player receiving medical attention is defined as a 'medical attention' injury (Fuller et al. 2006). A third subgroup of injury is reportable

in rugby union - non-fatal catastrophic injuries – that refer to ‘a brain or spinal cord injury that results in permanent (> 12 months) severe functional disability’ (Fuller et al. 2007, p. 329).

Consensus statements provide detailed approaches for injury surveillance studies within rugby, cricket and football. However, these approaches are not suitable where several diverse sports are being compared (Junge et al. 2008). The International Olympic Committee (IOC) injury surveillance system for multi-sports events was founded on the definition and data collection procedures in studies of football injuries (Fuller et al. 2006). The IOC definition of injury refers to ‘any musculoskeletal complaint newly incurred due to competition and/or training during the tournament that received medical attention regardless of the consequences with respect to absence from competition or training’ (Junge et al. 2008, p. 414). Injuries become reportable where they fulfil the following criteria: 1) musculoskeletal complaint or concussion (injuries), 2) newly incurred or re-injures, 3) incurred in competition or training, 4) incurred during the tournament, and 5) exclusion of illnesses and diseases (Engebretsen et al. 2010).

1.10 Recurrent Injury

Fuller and Bahr et al. (2007) have outlined the definition and recording of recurrent injury in injury surveillance studies. A recurrent injury (re-injury) is defined as an injury of the same location and type, which occurs after an

athlete returns to full participation from the previous injury. Hence, a re-injury is a repeat episode of a fully recovered index injury and an exacerbation is a worsening in the state of a non-recovered index injury. In agreement with the consensus statements in football and rugby, the IOC definition of recurrent injury states that pre-existing, not fully rehabilitated injury should not be reported (Junge et al. 2008). Recurrent injuries that refer to injuries of the same location and type should only be reported if the athlete has returned to full participation after the previous injury (Junge et al. 2008).

The advantage of the IOC definition of injury is that it allows expression of the incidence of injury in different formats and this allows comparison between studies that use the same definition. The IOC definition of injury reports injuries regardless of time-loss and this allows the effect of the full spectrum of injuries from mild contusions to fractures to be considered (Junge et al. 2008). This is particular pertinent to assessing the long-term consequences of injuries and the onset of OA. It is documented in the literature that injuries change the future risk of injuries (Fulton et al. 2014), and significant injuries are a risk factor for knee pain (Miranda et al. 2002) and OA (Muthuri et al. 2011). However definitions based on time-loss and medical attention can underestimate the impact of chronic injury. A typical chronic injury is where an athlete can continue to participate in training/competition but the athlete's performance is affected/restricted in volume and/or intensity due to pain and structural inhibition related to the

injury. Consequently, there are no whole days of time-loss, and this would be classified as a medical attention injury (i.e. no time-loss or restriction). As a medical attention injury the impact of the chronic injury would clearly be underestimated, where time or quality of training is being lost, and often for extended periods of time.

1.11 Methods for Recording Rates of Injuries, Exposure and Severity

The incidence rate of injuries is usually expressed as the number of new cases that develop during a given time period divided by the total person-time of observation (Kuhn et al. 1997). The incidence of injury is usually expressed as: 1) the number of injuries per 100 or 1000 athletes (Alonso et al. 2012; Engebretsen et al. 2010), 2) the number of injuries per 100 or 1000 exposures (Ranson et al. 2013), or 3) the number of injuries per 1000 hours training and / or competition (Fuller et al. 2006). However, there is a methodological dilemma in comparing the incidence of injury in different sports. Recording the incidence of injuries per athlete ignores the fact that a multi-sport tournament may consist of a different number of competitions per sport. The most accurate method of recording injuries appears to be based on an exposure-time related incidence (i.e. number of injuries per 1000 hours exposure). However, this method can be questioned if a comparison is made between one hour of netball and one hour of sprinting.

The IOC approach recommends recording exposure separately for competition and training. Time exposed to competition is difficult to

determine for multisport events where this no fixed match duration. Junge et al. (2008) recommends that an athlete's individual risk of injury in multi-sport events should be expressed and compared as injuries in competition per 1000 athlete participations. However, this ignores the fact that a multi-sport event is comprised of different frequencies and lengths of competition for each sport. Hence there are unique challenges in reporting injury incidence rates, and it is important to understand the methods being used, before meaningful comparisons can be made.

The severity of injury can be described on the basis of six criteria: working time lost, sporting time lost, nature of the sports injury, the duration and nature of treatment, permanent damage, and cost (Van Mechelen et al. 1992). Typically, severity of injury for time-loss injuries is presented in number of days, from the date the injury occurred, to the date the athlete returns to full training/competition. While this is a standardised measure it is important to be aware that injury severity recorded as days lost can be influenced by a number of different factors. For example, individual tolerance to pain and discomfort, where some players will return from a similar injury quicker than others; or the time of year or competitive event, where pressure to return to play and take part in big competitions or games (e.g. the Olympics) is great.

The recording of the type of injury, severity, location and mechanism of injury is subject to potential bias from the recorder. Injuries may be

recorded prospectively immediately at the time of injury (Willick et al. 2013) or they may be subject to potential recall bias by asking participants to recall past injuries retrospectively (Junge & Dvorak 2000). Injury data may be recorded by trained health care professionals such as a doctor or physiotherapist (Al-Shaqsi et al. 2012; Nysted & Drogset 2006) or by individuals without any medical training such as the coaches, or observers positioned in the crowd, or by the athlete/individual (Jacobson & Tegner 2007; Wekesa et al. 1996).

1.12 Rates and Nature of Injury by Sport

A total of 1362 injuries and 758 illnesses were reported during the 2012 Olympic Games in London. This resulted in an incidence rate of 128.8 injuries and 71.7 illnesses per 1000 athletes. The greatest risk of injury was in taekwondo, football, BMX, handball, mountain bike, athletics, weightlifting, hockey, and badminton. The lowest risk of injury was in archery, canoe slalom and sprint, track cycling, rowing, shooting and equestrian. Time-loss injuries accounted for 35% (n = 482) of the injuries incurred. Athletes were estimated to be absent from training or competition for than one week due to 174 (13%) of the injuries incurred. These injuries included 10 shoulder, elbow and knee dislocations (in hockey, football, judo, BMX and weightlifting); 38 muscle strains, of which 24 were thigh strains (mostly in athletics); 24 fractures (4 in running events); 8 Achilles, knee and shoulder tendon ruptures (in athletics, badminton, handball and basketball); 47 ligament sprains (across all joints and sports) and 15 knee

sprains, including 6 ACL and 1 PCL ruptures (in fencing, handball, judo, wrestling, badminton, table tennis, tennis and football) (Engebretsen et al. 2013).

A total of 287 injuries and 185 illnesses were reported during the 2010 Winter Olympic Games in Vancouver. This resulted in an incidence rate of 111.8 injuries and 72.1 illnesses per 1000 registered athletes. The greatest risk of injury was in bobsleigh, ice hockey, short track, alpine freestyle and snowboard cross. The lowest risk of injury was in Nordic skiing events (biathlon, cross country skiing, ski jumping, Nordic combined), luge, curling, speed skating and freestyle moguls. The most common injury locations were the head / cervical spine and the knee. Injuries were fairly evenly distributed between training (54.0%) and competition (46%). Of the 297 injuries incurred, 22.6% resulted in an absence from training or competition. There was no difference in the overall incidence proportion rate between the Winter 2010 Olympic Games in Vancouver and the Summer Olympic Games, held in London in 2013, with 11% of the athletes incurring an injury during the games, and 7% incurring an illness (Engebretsen et al. 2013; Engebretsen et al. 2010).

The frequency and the nature of sports injuries and illnesses were recorded during the 2009 International Association of Athletics Federations (IAAF) World Championship in Athletics in 2009 in Berlin, Germany (Alonso et al. 2010). The total number of injuries incurred was 236, with

262 injured body parts resulting in an injury incidence rate of 135.4 injuries per 1000 athletes. Of these injuries, 80% affected the lower extremity. The majority of injuries were incurred during competition (85.9%), and 80% of the injuries affected the lower extremity. The predominant cause of injury was overuse (44.1%). Approximately 43.8% of all injuries were time-loss injuries. The most commonly injured body part was the thigh (25.6%), the lower leg (21.0%) and the knee (9.5%). The trunk accounted for 13.0% of all injuries. The most frequent types of injuries were muscle strains (20.1%) and muscle cramps (21.6%), followed by skin laceration (18.3%), tendinosis (10.8%), and sprain (6.23%). The most common diagnosis was thigh strain (13.8%), lower leg laceration (8.6%), and muscle cramps of the thigh (8.2%), and lower leg (6.3%).

1.13 Prevalence of Injury

This is a cross-sectional study and this type of study design is the best way to determine prevalence (Mann 2003). The various consensus statements for recording the incidence of injury will not be adopted in this study because these methods require a cohort study design. In this study, the prevalence of injury will be recorded according to: 1) the percentage of injured athletes, and 2) the mean number of injuries per athlete. Injury will be reported according to sports injury (training and competition), non-sports injury (unknown and other type of injury) and the total number of injuries combined.

1.14 Summary of Literature Review

Epidemiological studies have largely focused on the prevalence or progression of radiographic knee OA in community-based populations. Previous studies have supported the claim that knee OA in occupational groups such as miners is a recognized occupational disease. It is known that high-volume exercise training and injury may increase the risk of developing OA, yet to date, there is virtually no evidence to determine the long-term sequelae and consequences of practising elite sport. Further cohort studies are needed to help to determine if the onset of OA in professional athletes should also be classified as an occupational disease. Although there is sound evidence to indicate the putative risk factors associated with the onset of pain and OA at the knee joint, it is yet to be proven if there is an association between joint hypermobility and OA. Further research may have implications for future prevention by helping us to understand better the risk factors associated with the onset of pain and OA at joint sites commonly affected by this disease.

1.14 Research Aims

1.14.1 Primary Study Aims

I. To describe the injury patterns, prevalence of pain, and self-reported physician-diagnosed osteoarthritis in Great Britain's Olympians;

II. To determine in Great Britain's Olympians aged 40 years and older the risk of pain and self-reported physician-diagnosed osteoarthritis at the hip, knee, and the lumbar spine;

III. To identify the individual risk factors associated with joint pain and self-reported physician-diagnosed osteoarthritis in Great Britain's Olympians aged 40 years and older.

1.14.2 Secondary Study Aims

I. To design and validate self-reported line drawings for assessing joint hypermobility using the modified Beighton score criteria ($\geq$ 4/9);

II. To determine if joint hypermobility is a risk factor or protector for the onset of pain and self-reported physician-diagnosed osteoarthritis in Great Britain's Olympians aged 40 years and older;

III. To identify if there are particular injury patterns associated with pain and self-reported physician-diagnosed osteoarthritis in Great Britain's Olympians aged 40 years and older.

1.15 Research Questions

1.15.1 Primary Research Question

I What is the level of risk and what are the contributing risk factors for joint pain and self-reported physician-diagnosed osteoarthritis in Great Britain's Olympians aged 40 years and older?

1.15.2 Secondary Research Questions

I. Is joint hypermobility a risk factor or protector from the onset of pain and self-reported physician-diagnosed osteoarthritis in Great Britain's Olympians?

II. Is joint hypermobility a risk factor for injury in Great Britain's Olympians, and if so, at which joint/s?

2.0 METHODOLOGY

2.1 Literature Search

2.1.1 Strategy

The literature review began by searching the title/abstract of the following electronic databases: Ovid, Pubmed, Embase, and PEDro from January 1993 to April 2015, or their respective beginning. The search strategy was limited to the English language, but incorporated both British and American spellings using Boolean words (‘and’ / ‘or’), and the following key words: osteoarthritis, osteoarthrosis, joint space narrowing, osteophyte, or degenerative joint disease. The results of the initial search were combined with the following additional words: cohort study, prospective study, prevalence, relative risk, or cross-sectional study. Several further specific searches were undertaken using the following key words: knee pain, knee arthritis, knee osteoarthrosis, knee injury, occupation or physical activity, body mass index, physical activity, finger ratio, age, gender or sex, radiographic, Beighton score, joint hypermobiity, and joint hypermobility syndrome. Periodic searches were undertaken to ensure new relevant material was referenced. An example of the literature search strategy that was carried out is included in Appendix B.

2.1.2 Identifying the Evidence

A systematic search of the aforementioned electronic databases identified potential relevant studies. After all the titles and abstracts of each paper had been screened, irrelevant citations were excluded. The

full copies of all potentially relevant citations were downloaded in PDF form from the electronic source. In those instances where the electronic copy was unavailable, the hard copy of the article was accessed via the Nottingham University Library, or placed on order in an electronic format from the British Library. The search then proceeded by sifting through the bibliographies of the relevant journal articles to identify any additional sources of information. Background papers that set the clinical scene were then accessed, but the highest level of evidence for the risk factors associated with the onset of osteoarthritis (OA) and pain was prioritised. A detailed assessment of the full text was used to exclude studies that were not relevant to the subject in question.

2.2. The Great Britain's Olympians Study

2.2.1 Type of Study

This was a cross-sectional study with an internal nested case-control study.

2.2.2 Study Participants

The participants in this study were individuals who have represented Great Britain (GB) at the Summer and / or the Winter Olympic Games. To qualify as a GB Olympian, a participant must have represented GB according to his or her parentage, birthplace, residence, and / or ancestry (Anon 2013). Participants must have been from one of the Home Nations (England, Scotland, Wales, or Northern Ireland), or three Crown dependencies (Isle of Man, Jersey, or Guernsey), or a British

overseas territory with membership of the British Olympic Association (BOA) (Anon 2010). Participants may have dual nationality, or they may have changed nationality, but they must have held a British passport at the time of competing for Great Britain. Where they had been eligible, participants must have stopped competing for a former country where eligible for a minimum period of three years before representing GB in an event recognised by the International Olympic Committee (Anon 2004). Participants were excluded from the study if they met any of the following criteria: psychiatric illness, severe dementia, terminal illness, or deceased. This information was gathered from questionnaires being returned from family members indicating that a participant was either deceased or had one of the above impairments. Members of the British Royal Family who have represented GB in the Olympic Games were excluded from this study.

2.2.3 Recruitment of Participants

The recruitment of GB Olympians involved two steps: 1) initial contact was made by placing an advertisement for the study (see Appendix C) in the BOA membership magazine, and 2) by distributing a letter by post (see Appendix D/E), or email (see Appendix F) inviting GB Olympians listed on the BOA Olympian database the opportunity to complete and return the Olympian questionnaire. The Olympian database holds the names and contact details of competitors (*N* = 2,862) who have represented GB at the Summer and / or the Winter Olympic Games. Members of the GB London 2012 Olympic Men's

Football Team were omitted from this database because the Professional Footballers' Association refused permission for the BOA to register these players.

The BOA Athletes' Commission supplied the contact details for the purpose of mailing the Olympian questionnaire. The BOA and the BOA Athletes' Commission gave permission for the study advertisement to be addressed from the BOA Director of Sport Services, and the Chair of the BOA Athletes' Commission. The letter of invitation was addressed from the Chair of the BOA Athletes' Commission and the Director of the Arthritis Research UK Centre for Sport, Exercise, and Osteoarthritis. The BOA Athletes' Commission endorsed the study by allowing their logo to be used in the email inviting GB Olympians to participate. The letter of invitation was enclosed in A4 sized envelopes that were franked with their logo by the BOA Athletes' Commission.

2.2.4 Data Collection Measurements

The Olympian questionnaire was designed to collect key data measurements as shown in Table 6.

Table 6: Olympian Questionnaire - Key Data Measurements

Age:	Recorded in years only to avoid identifiable information.
Gender:	Categorised into male or female.
Height:	Measured without shoes on in feet and inches or centimetres.
Weight:	Reported without shoes, wearing light clothing only in stones and pounds or kilograms.
Body Mass Index (BMI):	Defined as weight in kilograms divided by the square of the height in metres (kg/m^2). GB Olympians were classified into four categories using the World Health Organisation (2004) BMI categories of: underweight (< 18.50), normal weight (18.50-24.99), overweight (pre-obese) (≥ 25.00), and obese (≥ 30.00).
Ethnicity	Categorised into specific ethnic groups for use in England by the Office for National Statistics (2013). Categories included: White (English, Welsh, Scottish, Northern Irish), Black African, Black British, Black Caribbean, Mixed (White & Black African), Mixed (White & Asian), Mixed (White & Black Caribbean), Asian / Asian British (Indian, Pakistani, Bangladeshi, Chinese), and Other.
Limb Dominance:	Recorded upper and lower limb dominance for participating in athletic sports career according to: 1) right dominance, 2) left dominance, or 3) equally proficient.
Occupational Risk:	Occupational risk in sport was measured according to the sport participated in at Olympic level. Occupational risk outside of sport was examined according to job titles that were matched on the basis of being: a) manual, b) semi-manual, or c) non-manual. Occupational risk was segregated according to whether the sports / employment was part-time (</= 20 hours per week) or full-time (> 20 hours per week).
Levels of Physical Activity:	Type of sport and level of participation was recorded per average hours of training per week / year. Level of participation was categorised into: a) school level, b) club level, c) national level, d) international level, e) post-international level, and f) other.
Previous Surgery:	Recorded type of surgery, body part affected, age at time, and the reason for surgery.
Joint Injury:	Recorded the type of injury, the body part involved, competitor's age, the sport they were involved in at the time of injury, whether it was training or competition related, or alternatively a non-sporting injury[i)].
History of OA:	OA was defined as self-reported physician-diagnosed OA or degenerative joint disease. A second question extended the definition to a diagnosis made by any other healthcare provider. The following information was recorded: joint/s affected**;** age at the time of diagnosis and the last year of experiencing symptoms**;**

	investigations and treatment received.
Symptoms:	The level of pain was recorded using a self-report visual analogue scale (VAS) of between 0-100 millimetres in length. Symptoms were defined by recent pain (i.e. pain, aching, discomfort and/or stiffness but not including pain due to feverish illness such as 'flu) that has lasted for most days of the previous month, or most days for at least three months.
Heberden's Nodes:	Firm/knobbly swelling on the back of the fingers was self-recorded using finger diagrams[II)].
Index-Ring Finger Length Ratio (2D: 4D):	Finger patterning was self-recorded using pictures[III)] to demonstrate different index-ring finger length patterns. These patterns were split into three categories described by W. Zhang et al. (2008): type 1 (index-finger is longer than ring-finger), type 2 (both fingers are equal), and type 3 (index-finger is shorter than the ring-finger).
Knee Alignment:	Recorded using varus-valgus knee mal-alignment drawings[IV)] (i.e. straight legs, bow-legged or knock-knees) developed and validated by the Department of Academic Rheumatology at Nottingham City Hospital (Ingham, et al. 2010). GB Olympians were asked to score both legs now and in their 20's retrospectively.
Joint Hypermobility:	Measured using a newly developed self-report line drawing assessment tool[V)] (refer to chapter 3). This tool measured joint hypermobility according to the criteria used in the 9-point modified Beighton system. A cutoff threshold of $\geq$ 4/9 was used to categorize GB Olympians with generalised joint hypermobility. Joint hypermobility was scored now and in their 20's retrospectively.
Quality of Life:****	Measured using the Short-Form (SF) 12 Health Survey. The SF-12 was included as part of plan A - to compare the results with data previously collected from the local community population. The SF-12 measured two summary scores: 1) the Physical Component Summary Score (PCS), and 2) the Mental Health Component Summary Score (MCS) (Jenkinson et al. 1997).

i) Injury coding menus were developed and validated as part of the Injury Illness Surveillance Project in the Academic Orthopaedics, Sports Medicine and Trauma Department at the University of Nottingham (by Debbie Palmer-Green). The results have yet to be published.
ii) A set of self-reported pictures of Heberden's and Bouchard's nodes were developed and validated in a community population by O'Reilly et al. (1999).
iii) A self-reported 2D4D instrument has been developed and validated in the Academic Rheumatology Department at the Nottingham City Hospital. However it has yet to be validated in population-based research (Ingham 2010).
iv) A self-reported instrument of knee mal-alignment was developed and validated in a community population by Ingham et al. (2010).
v) A self-reported instrument of joint hypermobility using the Beighton system was developed and validated as part of this thesis – see chapter 3.

2.2.5 Design of the Questionnaire

The Olympian questionnaire was designed in two formats: 1) a paper-based version (see Appendix G), and 2) a web-based version (see Appendix H) hosted by Bristol University Survey. Both versions were subjected to a process of review (see Figure 1). The content and clarity of the Olympian questionnaire were reviewed in a Patient Public Involvement (PPI) focus group interview at the University of Nottingham with local residents. Suitable recommendations were fed back into the redesign of the Olympian questionnaire. The Committee at the BOA Athletes' Commission (*N* = 14) also then reviewed the Olympian questionnaire, and minor alterations were subsequently made. The Olympian questionnaire was assessed as part of two pilot studies. There was a final review by PPI members, and the Chair of the BOA Athletes' Commission.

The paper copy of the Olympian questionnaire was restricted to no more than five pages of double-sided A3 paper to ensure that the cost of printing was within the allocated budget. The paper copy was printed in colour, on 100 gsm uncoated paper, folded, and saddle stitched with two wires and a trimmed flushed finish. Text boxes were incorporated into the design of the questionnaire to avoid limiting the range of replies. The time taken to complete the Olympian questionnaire was reduced in order to maximise the potential return rate. This was achieved by: 1) using a series of tick boxes, and 2) using drop down menus in the web-version. The codes for the drop down menus are shown in Appendix I.

The Olympian questionnaire is divided into nine sections, as described in Table 7.

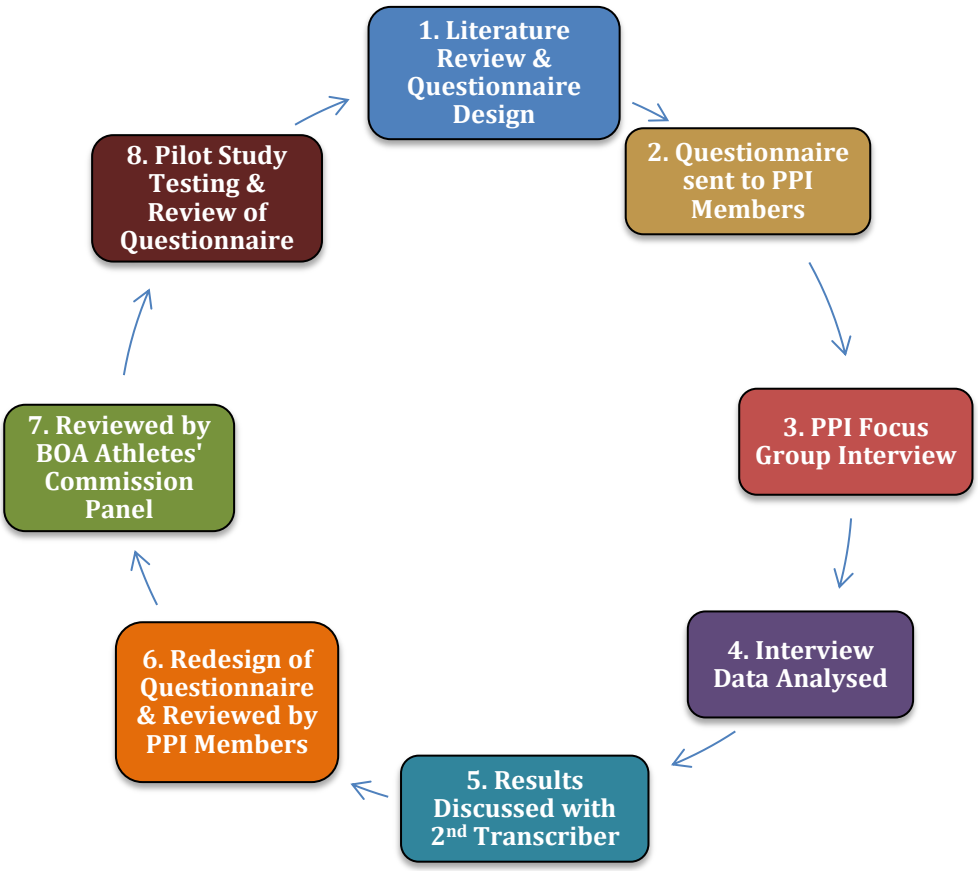


Figure 1: The Process of Reviewing the Olympian Study Questionnaire

Table 7: Design of the Olympian Questionnaire

1. About you:	The first section was designed to collate information on known risk factors for OA, including age, gender, ethnicity, occupational risk, and body mass index (BMI). This section also records whether or not GB Olympians were retired from their athletic sports career, and if so, their reason/s for retirement. A list of reasons for retirement was constructed following Patient Public Involvement and review with the BOA Athletes' Commission.
2. Your sports & activities:	Section two records the exposure to exercise or physical activities participated in at school level, club level, national level, international level, and any other level. A second table was used to record physical activity levels, the type of training and surface trained on, and the mean hours of exposure to training measured in hours per week / weeks per year.
3. Your health:	Section three invites GB Olympians to report if they have one or more comorbidities from a list of medical conditions which allowed odd ratios to be adjusted for comorbidities (Nevitt et al. 2008). GB Olympians were requested to complete a pain manikin denoting whether or not they have experienced pain, aching or stiffness anywhere in the body on most days during the past month. The question format was adopted from a previous study that collected from a local community population data on knee pain (Ingham 2010). The prevalence of pain is known to be affected by question content (O'Reilly et al. 1996). A second question measured the prevalence of pain experienced over a three-month period.
4. Your injuries:	Section four records the type of injury, the body part involved, the athlete's age and the sport he or she was involved in at the time of injury, and whether it was a training or competition-related injury, or a non-sporting injury. Drop down menus were developed to record this information on the web-based version of the Olympian questionnaire. These injury-coding menus (see Appendix I) were adapted from the Injury Illness Surveillance Project[i)], and the Orchard Sports Injury Classification System (OSICS) (Orchard et al. 2010). Each coding item was subject to Patient Public Involvement, and a subsequent pilot study to ensure medical terminology was recoded in plain English. Absences due to illness were excluded.

Table 7 Cont.

5. Your hands:	Section five invites GB Olympians to assess their hands for Heberden's and / or Bouchard's nodes that appear as a firm knobbly swelling on the back of their fingers. There are pictures[ii)] demonstrating the appearance of these nodes (O'Reilly et al. 1999), and all GB Olympians will be requested to identify which of their joints are affected. GB Olympians will also be asked to indicate the length of their index-finger in comparison to their ring-finger on both hands, using an alternative set of pictures[iii)]. These pictures were developed in the Academic Rheumatology Department at the Nottingham City Hospital and were used in a previous study by Ingham (2010).
6. Your knees:	Section six invites GB Olympians to select from line drawings[IV)] validated in a previous study (Ingham et al. 2010) the one that matches the angle at their knees (i.e. straight legs, bow-legged or knock-knees). GB Olympians will be requested to score both of their legs now, and to indicate which picture best shows the angle of each of their legs in their 20's.
7. Your joints:	Section seven is designed to be a self-report measure of joint hypermobility[v)]. GB Olympians will be invited to select from a series of line drawings the one that matches the angle at various joints, using the modified Beighton score. GB Olympians will be requested to score their joints now and to choose which line drawings best show the angle of their joints in their 20's retrospectively.
8. Your family:	Section eight records if GB Olympians' immediate family (mother, father, brother and sister) have been diagnosed with OA, have had joint replacement surgery, or are known to have knobbly fingers.
9. About your general health:	Section nine is the Short-Form (SF) 12 which is a generic measure of qualify of life. The SF-12 is a shorter measure of the SF-36. The SF-12 has been reported to reproduce accurately the two summary components scores of the SF-36, the Physical Component Summary Score (PCS) and the Mental Health Component Summary Score (MSC) (Jenkinson et al. 1997).

i) Injury coding menus were developed and validated as part of the Injury Illness Surveillance Project in the Academic Orthopaedics, Sports Medicine and Trauma Department at the University of Nottingham (by Debbie Palmer-Green). The results have yet to be published.
ii) A set of self-reported pictures of Heberden's and Bouchard's nodes were developed and validated in a community population by O'Reilly et al. (1999).
iii) A self-reported 2D4D instrument has been developed and validated in the Academic Rheumatology Department at the Nottingham City Hospital. However it has yet to be validated in population-based research (Ingham 2010).
iv) A self-reported instrument of knee mal-alignment was developed and validated in a community population by Ingham et al. (2010).
v) A self-reported instrument of joint hypermobility was developed and validated as part of this thesis – see chapter 3.

2.2.6 Patient Public Involvement

The Patient Public Involvement (PPI) panel consisted of six female volunteers aged between 30 and 78 years. All PPI members resided in Nottinghamshire. The volunteers received a paper copy of the participant information sheet (see appendix J), the letter of invitation to take part in the Olympian study (see Appendix D), and a paper copy of the Olympian questionnaire (see Appendix G) prior to attending a focus group interview. The volunteers were sent an interview schedule (see Appendix K) explaining the format of the interview, which was held at the Queen's Medical Centre in Nottingham. The purpose of the meeting was to ensure that the study documentation was clear and written in plain English. The interview began with formal introductions and was followed by a ten-minute presentation explaining the purpose of the Olympian study. Volunteers were reminded of their rights to consent and anonymity. Two assistants took field notes during the interview regarding the views of the volunteers. A cassette recorder was also used to record responses. The cassette recorder was positioned in the room in such a way as to avoid acting as a visual distraction.

The Principal Investigator attempted to use open-ended and non-directive questions to prevent the volunteers feeling that there was a correct answer, or a particular answer that the Principal Investigator was looking for. The duration of the focus group interview was guided by the volunteers' responses but adhered to the maximum time available of 90 minutes. To demonstrate to the volunteers that their

responses were valued, the Principal Investigator attempted to be attentive throughout. At the same time, he took care to limit interference by attempting to allow sufficient time for each question, by avoiding interruption, by attempting to maintain neutral body language and by using neutral prompts. Interviews were listened to and salient points were transcribed into Microsoft Word 2013. Data was split into paragraphs and each line was assigned an identification number. For example, VAQ1L4 referred to volunteer A, question 1, line 4. The interview transcripts were condensed by eliminating and augmenting categories that were similar in content.

The two sets of field notes were cross-referenced with the cassette recording. There were several amendments to the Olympian questionnaire following the PPI focus group interview (see Table 8). These recommendations were verified by two research assistants following a review of their field notes. These amendments were then made and the study documents were returned to the PPI members once more for verification. The PPI members were subsequently sent access to the web-based Olympian questionnaire and feedback was returned to the Principal Investigator by email. A second PPI review took place with the BOA Athletes' Commission (*N* = 14). The Chair of the BOA Athletes' Commission provided feedback by telephone to the Principal Investigator in respect of the web-based version of the questionnaire. A number of amendments were made following the review by the BOA Athletes' Commission (see Table 9)

Table 8: Amendments to the Olympian Questionnaire Following Patient Public Involvement

Original Content	Amendment
Front cover - As an Olympian, you have been invited to complete the Olympian Questionnaire…… Your responses will be kept strictly confidential and you will not be identified.	As an Olympian, you have been invited to complete the **Olympian Questionnaire…**…. **Your responses will be kept strictly confidential and you will not be identified** (bold lettering added)
Front cover - 15-20 minutes to complete the questionnaire	20 minutes to complete the questionnaire
Question 1.4 - Weight in stones and pounds	Weight in stone and pounds or kilograms
Question 1.5 - How much did you weigh in your 20's	How much did you **weigh in your 20's***?* (bold lettering added)
Question 1.7 - Which are your dominant limb/s for participating in your athletic sports career	Which are your **dominant limb/s** (bold lettering added) for participating in your athletic sports career
Question 1.9 - Please indicate which of the following was the main reason/s for retiring from your athletic sports career:	Please indicate which of the following were the **main reason/s for retiring** (bold lettering added) from your athletic sports career.
Question 3.2 - Are you currently taking any medication	Are you currently taking any **medication** (bold lettering added)
Question 3.3 - If you answered yes, do you take any of the following medications?	If you answered yes, do you take any of the following **medications**? (Bold lettering added)
Question 3.4 - We would now like you to consider any recent pain you have experienced anywhere in your body. By pain we mean pain, aching, discomfort and / or stiffness that has lasted for most days of the previous month. Please do not include pain due to feverish illness such as the 'flu. If you have not had any body pain that has lasted for most days of the previous month, please tick the box and move to question 3.5	We would now like you to consider **any recent pain you have experienced anywhere in your body** (bold lettering added). By pain we mean pain, aching, discomfort and / or stiffness **that has lasted for most days of the previous month** (bold lettering added)**.** Please do not include pain due to feverish illness such as the 'flu. If you **have not** (bold lettering added) had any body pain that has lasted for most days of the previous month, please tick the box and **move to question 3.5** (bold lettering added)

Table 8 Cont.

Question 3.5 - We would now like you to consider any recent pain you have experienced anywhere in your body for most days for at least three months. Please show where you have had this type of pain by marking the body chart above with the letter P	We would now like you to consider **any recent pain you have experienced anywhere in your body** (bold lettering added) or most days for at least **three months** (bold lettering added). Please show where you have had this type of pain by marking the body chart above with the letter P
Question 4.1 - 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	Have you ever sustained a significant injury that **caused pain for most days during a one-month period** (bold lettering added) and for which you consulted a medical professional or a health provider such as a general practitioner
Have you ever been diagnosed with osteoarthritis in any of your joints by a physician (for example, your GP)	Have you ever been diagnosed with osteoarthritis in any of your joints **by a physician** (bold lettering added) (for example, your GP)
Have you ever been diagnosed with osteoarthritis in any of your joints by any other healthcare provider (for example, a physiotherapist)?	Have you ever been diagnosed with osteoarthritis in any of your joints **by any other healthcare provider** (bold lettering added) (for example, a physiotherapist)?
Please indicate which diagram best shows the length of your left index-finger in comparison to your left ring-finger *(please tick the appropriate box)*	Please indicate which diagram **best shows the length of your left index-finger in comparison to your left ring-finger** (bold lettering added) *(please tick the appropriate box).* The Index-finger and ring-finger were labelled with the letter I and R on the picture diagrams
Question 7.5 - Which picture above (A, B, or C) best shows how far you can bend forwards without bending your knees?	Added - (If it is not safe for you to attempt this, how far forwards can you reach forwards in sitting (i.e. option D, E or F)?

Table 9: Amendments to the Olympian Questionnaire Following Review with the BOA Athletes' Commission

Original Content	Amendment
Front page - current and retired Great Britain's Olympic Athletes	Great Britain's Olympians
Question 1.8 – Are you retired from professional sport	Change of wording to: Are you **retired** (bold lettering added) from your athletic sports career
Question 1.9 – Options for retiring: 1) achieved all that was possible, 2) decline in capability i.e. fitness, 3) alternative career, 4) injury – recurrent, 5) injury – one off major injury	Two additional options added: 6) deselected, and 7) other reason (please describe below)
Question 1.10 - If you retired from your Olympic sports career due to injury, please specify below the location (e.g. right knee) and nature of injury (e.g. ligament)	If you retired from your athletic sports career due to injury, please specify below the **location** and **nature of injury** (bold lettering added)
Question 2.1 Options for level of sport participated in: school, amateur, professional, since retiring from professional career	Options changed to: school, club, national, international, post international, other

2.2.7 Piloting the Questionnaire

The purpose of the pilot study was to assess the usability of the paper and web-based version of the Olympian questionnaire. Volunteers were recruited from staff members (*N* = 12) within the School of Medicine (*n* = 8) and the School of Nursing (*n* = 4) at the University of Nottingham using a pilot study advert (see Appendix L) placed on the notice board. Two lecturers in the School of Nursing brought the study advert to the attention of staff and students. Volunteers were issued with a pilot study participant information sheet (see Appendix M) and consent form (see Appendix N). Volunteers were requested to write down any questions and/or difficulties arising with the content, language and layout of the Olympian questionnaire. This information was then used to design the master version.

A number of minor amendments were made following the piloting of the Olympian questionnaire. The online version of the questionnaire was amended, by reconfiguring the date in the drop down menus. Pictures were loaded into the web questionnaire by using a Uniform Resource Locator (URL) link from an external network. However, this URL link was problematic because of the Bristol University Survey firewall prohibited pictures from an authorized external source appearing in the web-version of the Olympian questionnaire. This problem was overcome by loading the pictures into a new URL link embedded into the Centre for Sport, Exercise and Osteoarthritis webpage at the University of Nottingham.

2.2.8 Distribution of the Olympian Questionnaire

The distribution of the study questionnaire was divided into the following four stages:

1) On the 22nd May 2014, the BOA Athletes' Commission distributed an email on behalf of the Principal Investigator to 2181 GB Olympians who had a registered email address on the BOA Olympian database. Emails were sent to GB Olympians living in the United Kingdom (*n* = 1992) and those living overseas (*n* = 189) inviting them to use the enclosed URL link to securely access the web-based questionnaire, which was hosted by the Bristol University Survey. The invitation included a second URL link, which gave access to a web-based participant information sheet (see Appendix O). GB Olympians were advised to read the participant information sheet before completing the web-based questionnaire, and should they decide to participate, they were instructed to enter their unique identification number included in the invitation to take part. After one week, the BOA Athletes' Commission distributed a reminder to complete the web-based questionnaire.

2) On the 30th May 2014, paper copies of the study questionnaire were delivered to the BOA headquarters in London ready to be distributed to those GB Olympians (*n* = 510) with an inactive email address, or no registered email address on the BOA Olympian database. Each paper questionnaire was packaged into an envelope, which contained a letter

of invitation to complete the study questionnaire, a participant information sheet, and a self-addressed return envelope prepaid by the business response service. The Principal Investigator was responsible for the preparation and transportation of these envelopes to the BOA Athletes' Commission headquarters in London. On arrival, the Principal Investigator was supplied with the names and addresses of each GB Olympian. These contact details were printed on sticky address labels. The Principal investigator was responsible for applying the label with the correct contact address on to the front of each envelope. This was achieved by matching the unique identification number located on the top right hand corner of each sticky label with the number applied to the front of each envelope.

3) On the 3rd July 2014, a second mail out took place to distribute paper questionnaires to those GB Olympians (*n* = 2230) living in the UK who had not returned a completed questionnaire. The paper questionnaires were prepared in advance and delivered to the BOA headquarters in London by the Principal Investigator. On arrival, the BOA Athletes' Commission supplied the address labels that were added to each envelope. 2172 paper questionnaires were franked and distributed the following morning. 58 of the 2230 paper questionnaires were not sent because of either a missing address or the GB Olympian was known to be deceased.

4) On the 12th August 2014, a third mail out took place to distribute paper questionnaires to GB Olympians (*n* = 208) living outside the United Kingdom who were yet to return a completed questionnaire. The letter of invitation was amended to explain why the Principal Investigator was unable to apply the correct postage to the enclosed envelopes to enable the study questionnaires to be returned from outside of the UK. Alternatively, GB Olympians living overseas were asked to complete the web-based questionnaire or the enclosed paper questionnaire. A contact email address was provided to allow GB Olympians to claim back the cost of posting the paper questionnaire back to the UK. The academic supervisors sought the funding to cover the costs of the mail-out of the questionnaires. It was the responsibility of the Principal Investigator to ensure: 1) the study ran within the allocated budget, and 2) to prepare the distribution of the paper questionnaires. The Principal Investigator arranged for the printing and binding of the paper questionnaires, printing the participant information sheets, the letters of invitation, and the prepaid self-addressed return envelopes. The Principal Investigator prepared the questionnaires for mailing from the BOA headquarters in London.

2.2.9 Ethical Consideration

An application was submitted to the Faculty of Medicine and Health Sciences (FMHS) Research Ethics Committee at the University of Nottingham on 17th January 2014. The study was approved on the 13th February 2014. A number of minor changes were recommended

following a review by PPI, the BOA Athletes' Commission, and following piloting-testing the letter of invitation, participant information sheet, and the Olympian study questionnaire. A verbal request to make the necessary amendments to these aforementioned documents was granted from the Chair of the FMHS Research Ethics Committee. A notice of amendment was submitted successfully to account for a major amendment to the study protocol to allow the use of internal rather than external controls. The Principal Investigator was responsible for working in tandem with the BOA Athletes' Commission to ensure that both the research institution and the BOA Athletes' Commission met their obligations in respect to the GB Olympians. A number of methods were used to avoid the disclosure of personal and sensitive data (see Table 10).

Table 10: Protection of Confidentiality

	Methods to Protect Confidentiality
Informed Consent	The letter of invitation and the participant information sheet make it explicit that by completing and returning the Olympian questionnaire GB Olympians gave implied consent. GB Olympians are informed that if they choose to complete and return the Olympian questionnaire they were consenting to have their details stored for future analysis. Their data will be available to other future users within the named research institution who are not part of this study. GB Olympians were informed that they were giving authorization for inclusion of their data in public release datasets, such as journal articles and press releases. The methods used to avoid the disclosure of GB Olympians personal and sensitive data will be discussed in the following sections.
Participant Anonymity	A unique identification number was supplied to each GB Olympian, who was requested to use this in correspondence, including submission of the on-line and paper questionnaires. GB Olympians were requested to record their age in years rather than by date of birth to protect their anonymity. Implied consent was used to avoid the use of personal signatures that could identify the GB Olympian.
Encrypting Files	The letter of invitation includes the Uniform Resource Locator (URL) also known as a web address. This allowed GB Olympians to access the web-based questionnaire. The URL was protected by Secure Sockets Layer (SSL) encryption. The SSL secured the transmission of the questionnaire data via the Internet using a cryptographic system that secures a connection to the Bristol University Survey domain website. The questionnaire data was then encrypted during transmission from the Bristol University Survey website to the Principal Investigator. The data was downloaded into a Microsoft Office Excel spreadsheet and saved in an encrypted format on the University of Nottingham's computer system.

Table 10: Continued.

Disposal of Study Data / Documents	All hard copies of study data were securely stored and any additional copies were taken to the research institutions nearest point for shredding. Data was shredded in person by the Principal Investigator, and disposed of according to the research institution's policy on disposal of waste. The Principal Investigator was the contact person to assist GB Olympians to complete the Olympian questionnaire. Emails from GB Olympians to the Principal Investigator were sent to the Principal Investigator's University of Nottingham account, which was also protected by SSL. All emails were deleted and disposed of from the deleted email inbox.
Limiting Access to Identifiable Information	The master file that links GB Olympians unique identification number to their personal details was held by the BOA Athletes' Commission and not by the research institution. The research institution is responsible for holding the copies of the completed paper and online questionnaires. Access to questionnaires was limited to key study personnel at the named research institution. The Director for the Arthritis Research UK Centre for Sport, Exercise and Osteoarthritis is the gatekeeper for future users of the completed questionnaires.
Storing Data Securely	All hard copies of data are maintained in a locked filing cabinet within the Arthritis Research UK Centre for Sport, Exercise, and Osteoarthritis at the named research institution. Access to these files is limited to key study personnel only. The BOA Athletes' Commission is responsible for storage of the Master file that links the unique identification number to the GB Olympians' personal details.
Security of Computer Records	The responses from the web-based questionnaires are stored in an electronic file that is password-protected and stored under lock and key with the paper copies of the paper questionnaire. Access to these files is limited to key study personnel only.

2.2.10 Management of Questionnaire Data

2.2.10.1 Data Entry

The replies from each question and item on the Olympian questionnaire were entered into a spreadsheet in Microsoft Excel 2013 prior to being opened in SPSS version 16.0. This dataset was set up with a maximum of eight-character variable names to allow data files to be transferred between different versions of SPSS. Each variable name was given an abbreviated name. This ended in an ID number that corresponds to the number of the question as it is laid out in the Olympian questionnaire, for example, employ 1.11 (i.e. employment; section 1; question 11). The abbreviated names were used to cross reference data with individual questions to check for data entry errors. A second spreadsheet lists the variables in the Olympian questionnaire, the abbreviated variables' names that are used in SPSS, and the way in which the responses were coded. This information is labelled as the 'codebook' (Appendix P) and is stored in an electronic file to allow others to use the dataset, to understand what the abbreviations and numbers refer to, and the way in which the responses are coded.

2.2.10.2 Accuracy of Data Entry

The dataset was merged into SPSS and all data entry was double checked to ensure accuracy of data entry. Data was then checked for errors using SPSS to produce a summary of each variable and a breakdown of the range of responses. The minimum and maximum values were checked to determine how many cases fall into each of the

legitimate categories, and how many cases have out-of-range values for each item on the questionnaire. The number of valid and missing cases was examined and the Data Editor Window in SPSS was used to view cases with values that are out of range. The variable column that was coded as the identification column was used to locate any questionnaire with missing cases and / or error values. All of the returned questionnaires were selected and used to verify the accuracy of the data entered. Any errors found were corrected and recorded in a third spreadsheet. The knee alignment data was re-entered due to a typographical error in the column heading.

2.2.11 Statistics Analysis

Inferential statistics were performed in SPSS (SPSS for Windows Version 16.0, Chicago, Ill). The data file was coded for statistical analysis into 16 independent variables (see Table 11) and 6 dependent variables (see Table 12). The data file consists of 14 categorical independent variables, 2 independent variables on a continuous scale, and 6 categorical dependent variables. Several statistical techniques were used to analyse the questionnaire data and include: descriptive and graphical illustrations of the file, binary logistic regression, independent samples t-tests and a series of chi square test for independence.

Table 11: Independent Variables for Statistical Analysis

Independent Variables for Statistical Analysis		
Age*	Knee alignment in early life (20-29 years)**	Finger nodes**
BMI*	Index ring finger ratio**	Weight-bearing loading sports**
Gender**	Physical wellbeing*	Impact sport**
Hip pain**	Psychological wellbeing*	Widespread pain**
Lower back pain**	Significant joint injury**	Hypermobility in early life (20-29 years)**
Co-morbidities**		

*NB * = continuous variables; ** = categorical variables*

Table 12: Dependent Variables for Statistical Analysis

Dependent Categorical Variables for Statistical Analysis	
Knee pain	Knee osteoarthritis
Hip pain	Hip osteoarthritis
Lumbar spine pain	Lumbar spine osteoarthritis

2.2.11.1 Sample Size / Power Calculation

There is no single rule for the number of events (outcomes) per variable required to estimate logistic regression parameters (Courvoisier et al. 2011). Yet, it is generally accepted in the literature that there should be a minimum of 10 events per predictor variable (Peduzzi et al. 1996). For the purpose of univariate analysis, one in four individuals over 55-years having knee pain (Peat et al. 2001), with a significance level of 0.05 and a power of 80%, a minimum of 40 GB Olympians were required in order

to detect the difference between those with knee pain and those without.

For multivariate analysis, the sample size was approximately the sample size for univariate analysis multiplied by the number of covariates. Based on a maximum of twelve covariates in the logistic regression model, responses from 500 GB Olympians aged 40 years and older were each required to produce 10 outcomes per covariate. The estimated response rate of one in four questionnaires being returned is adequate to provide sufficient study power and was achievable based on the response rate from a previous study (Ingham 2010).

2.2.11.2 Injury Prevalence

The prevalence of injury was expressed as: 1) the percentage of injured athletes (see Figure 2), and 2) the mean number of injuries per athlete. Injuries are reported according to sports injury (training and competition), non-sports injury (unknown and other type of injury) and the total number of injuries combined. Based on the IOC consensus on recording injuries, if multiple body parts were injured during the same incident, multiple types of injuries occurred in the same body part, only the most severe injury was registered, however, with several diagnoses (Junge et al, 2008).

The formula for calculating prevalence of injury is shown in Figure 2:

$$\text{1) Percentage of injured athletes} = \frac{\text{Number of injured athletes}}{\text{Number of athletes}}$$

Figure 2: Formula for Calculating Percentage of Injured Athletes

2.2.11.3 Prevalence of Body Pain

Pain drawings (or body manikins) were used as a self-report screening instrument to record the location of pain. In the paper version of the Olympian questionnaire, question 3.4 requested that GB Olympians shaded their pain on most days of the past month within the outliers of the front and rear views of a blank body manikin. Question 3.5 requested that GB Olympians label the shaded area of pain with the letter 'P' to denote any recent pain lasting for most days for three months. These two definitions of body pain were subsequently combined to form a third definition of pain that was used in the statistical analysis of this study. Pain was defined as either "any recent pain GB Olympians had experienced anywhere in their body for most days for at least one month, or "any recent pain GB Olympians had experienced anywhere in their body for most days for three months".

Pain drawings were scored by placing transparent templates (see Figure 3) over the body manikin, a method shown to be repeatable (Lacey et al. 2005). These templates divide the body regions into 50

defined body areas, based on those in the Manchester definition of widespread pain (Macfarlane et al. 1996). In addition to these codes, the hand and foot regions were split to account for pain in either thumb or great phalanx. Pain on the body manikin was recorded using the following guidelines described by Lacey et al. (2005): 1) any mark (e.g. shading, scribble, cross or line) within a template area was scored as pain present, 2) any arrow touching a template area was to be scored as pain present, and 3) any marks or arrows outside (i.e. not touching) the pain drawing to be ignored. Points 1 and 2 in the above marking guidelines were adjusted to also include the letter 'P' where the GB Olympian had marked the pain manikin with the character letter but had not shaded the corresponding area. In the web-based version of the Olympian questionnaire, GB Olympians recorded pain using the body manikin code numbers to denote the body areas, as shown in Figure 3.

No distinction was made between unilateral and bilateral limb pain. The most severe joint was selected, if bilateral, for examining risk factors associated with the onset of pain or self-reported, physician-diagnosed OA. GB Olympians who made no mark on the pain manikin, but failed to tick 'no' to having had recent pain in question 3.4 in the Olympian questionnaire were recorded as missing data. The prevalence of body pain was calculated by dividing the percentage of GB Olympians who recorded pain in the different regions of the body by the sum of the number of GB Olympians who returned the Olympian questionnaire minus cases with missing data. The relative risk of different covariates

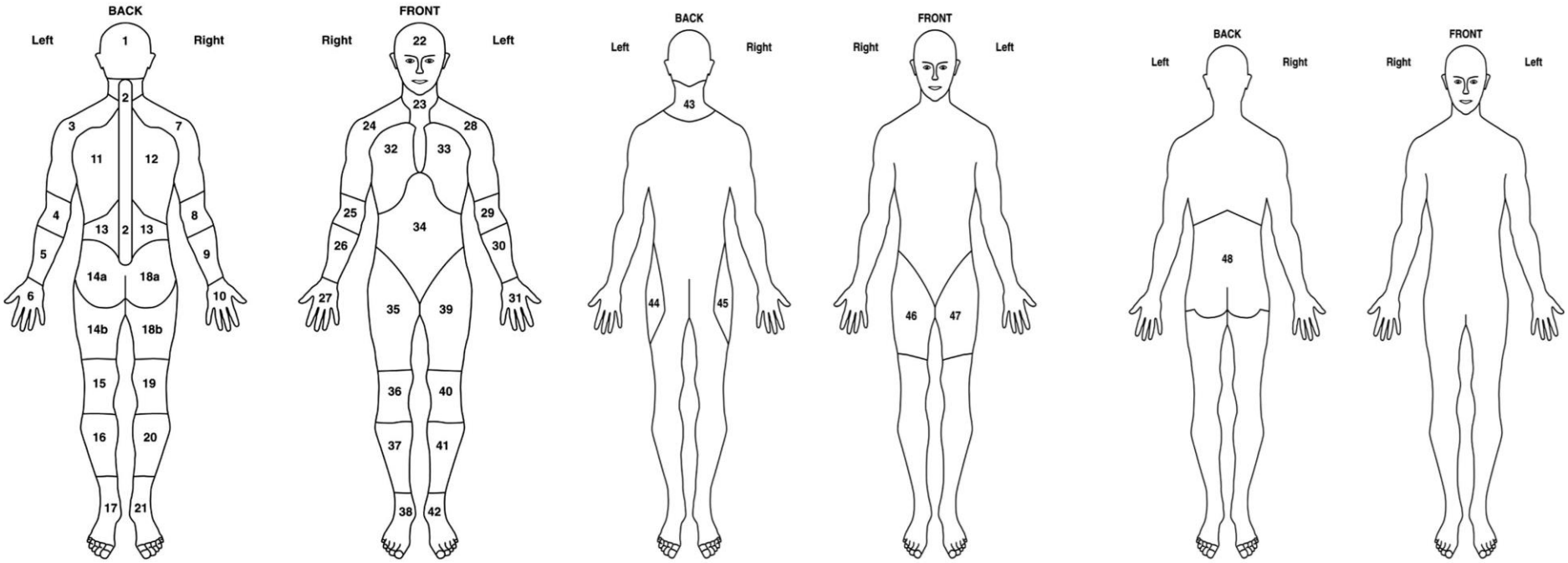
being associated with the onset of pain was reported using crude odd ratios (OR) and adjusted odd ratios (aOR) with 95% confidence intervals (95% CI). Statistical significance was inferred with $P < 0.05$, and the 95% CI didn't cross one.

2.2.11.4 Outcome of Body Pain

Pain was recorded as either being 'present' or 'not present'. The outcome (i.e. intensity) of pain was recorded on the visual analogue scale (VAS), and it was analysed as a continuous variable, with zero representing no pain, and ten representing the worse pain imaginable.

2.2.11.5 Prevalence of Osteoarthritis

The prevalence of OA was recorded by the presence of a self-reported, physician-diagnosis of OA. Great Britain's Olympians who failed to reply to whether or not they had been diagnosed with OA (questions 4.2 and 4.3) were counted as missing data and excluded, unless they had completed the table of information as part of questions 4.2 and 4.3 in the Olympian questionnaire. In this instance, data was extracted from the table of information confirming who had diagnosed them with OA and included in the data analysis. OA was dichotomized into 'yes' or 'no' and logistic regression analysis was repeated, body pain substituted with OA.



Widespread Pain **Neck and Hip Pain** **Lower Back Pain**

Figure 3: Body Manikin Illustrating the 50 Different Regions of Body Pain

(Lacey et al, 2005)

2.2.11.6 Building the Multivariable Regression Model

The purpose of analysing the covariates was to identify the individual factors associated with pain or self-reported physician-diagnosed OA in Great Britain's Olympians aged 40 years and older. Three separate models of binary logistic regression were constructed to examine the possible covariates that are associated with pain at the knee, hip and the lumbar spine. A further three models were constructed to examine the covariates associated with a self-reported physician-diagnosis of OA at the knee, hip and the lumbar spine. The strategy for building each of the six multivariable regression models is explained in greater detail by Hosmer et al. (2013). This method involved several steps including: purposeful selection of covariates and fitting a univariable logistic regression model for each covariate, fitting the multivariable regression model, refitting the multivariable regression model, and checking the fit of the model.

2.2.11.7 Purposeful Selection of Covariates

The first step of model development began by purposefully selecting relevant covariates of known clinical importance. Age, body mass index and gender were considered to be clinically relevant and were included in each of the univariable regression models (Silverwood et al., 2015; Blagojevic et al., 2010; Lachance et al. 2002; Miranda et al., 2002). The second step of model development involved performing a series of chi-square tests of independence to determine if any of the remaining

covariates were significantly associated with the dependent variable of interest. The odds ratios were also calculated for those variables exhibiting at least a moderate level of association.

A significance level of $P < 0.25$ was used to screen the initial variable selection based on the work by Mickey and Greenland (1989), who have shown that the use of a traditional significance level $P < 0.05$ frequently fails to identify variables known to be important. Each covariate was reviewed prior to constructing the final multivariable model to eliminate variables of questionable importance when using a significance level of $P < 0.25$ (Hosmer et al. 2013). Covariates with fewer than 10 events were excluded from each of the six final multivariable models of logistic regression.

2.2.11.8 Fitting the Multivariable Regression Model

All covariates identified for inclusion in the univariable regression model were fitted into the multivariable regression model. The importance of the covariates added during the second stage of model development based on a $P < 0.25$ were assessed, using the *p*-value of the Wald statistic and a traditional significance level of $P < 0.05$. The covariates that did not significantly contribute to the model were eliminated and a new smaller model was fitted. The covariates of known importance such as age, gender and body mass index remained in the model irrespective of their statistical significance.

2.2.11.9 Refitting the Multivariable Regression Model

The values of the estimated coefficients in the smaller model were compared to their respective values from the larger model. Any coefficient that changed by twenty per cent or greater was examined to determine if any of the excluded variables were important in terms of providing a necessary adjustment of the variables that remained in the model. Any such variable was returned to the multivariable regression model and this process continued until all of the important covariates were included in the model.

Each variable that was not shown to be statistically significant during stage two of model development was added one-by-one to the model and its significance was assessed by the Wald statistic *p*-value ($P < 0.05$). This helped to identify and include variables that make an important contribution in the presence of other variables, despite them not being significantly related to the dependent variable (Hosmer et al. 2013). This method was used to construct the preliminary results model containing all of the essential variables. A list of possible interactions was also constructed from which interactions among the variables in the model were assessed. Interactions were included if they were considered to be clinically relevant and statistically significant ($P < 0.05$). The final multivariable regression model was entered into SPSS using the forced entry method for data analysis in that all of the predictor variables were included in the regression model in one block, and parameter estimates were calculated for each block (Field 2005).

2.2.11.10 Checking the Fit of the Model

Preliminary analysis was undertaken to ensure there was no violation of the assumption of multicollinearity indicated by $r \geq .7$, a tolerance value of < 0.10, and a variance inflation factor (VIF) > 10. The adequacy of the final multivariable regression model was assessed by checking its fit using the Hosmer and Lemeshow Test, with a poor fit indicated by a significance value of less than 0.05 (Pallant 2007).

2.2.11.11 Covariates

2.2.11.11.1 Age

Age was treated as a continuous variable and assumed to be linear in the logit. A cut-off threshold of equal to or greater than 40 years was used as eligibility to be included in the data analysis for potential risk factors associated with pain or OA. This particular cut-off was used because the onset of OA tends to occur after the fourth decade of life. This cut-off method is also consistent with two previous studies examining the prevalence (O'Reilly et al. 2000) and the incidence (Ingham 2010) of knee pain in the community. To allow comparison with the results of previous studies within the literature, the covariate age was also categorised into: 40-59 years of age and over 59 years. The BOA Athletes' Commission was able to confirm the age of two individuals from the BOA Olympian database using the identification numbers supplied. There was no missing data on the web-version of the Olympian questionnaire because age was a mandatory field that

had to be completed before the Olympian questionnaire could be submitted.

2.2.11.11.2 Gender

Gender was dichotomised into male and female. For this covariate there was no missing data in either the paper or web-version of the Olympian questionnaire. Gender was a mandatory field. It had to be completed in the web-version of the Olympian questionnaire before it could be successfully submitted.

2.2.11.11.3 BMI

Body weight was recorded in either stones and pounds or kilograms. Height was recorded in either centimetres or feet and inches. BMI was calculated by first converting all height and weight values into centimetres and kilograms respectively. BMI was then calculated by weight in kilograms divided by the square of the height in metres (kg/m^2). A current BMI score was calculated and a past BMI in their 20's was estimated based on the data supplied. The advantage of categorizing the BMI variable by the WHO (2004) categories of under weight ($< 18.50\ kg/m^2$), normal weight ($18.50 < 25.00\ kg/m^2$), overweight ($\geq 25.00, < 30.00\ kg/m^2$), and obese ($\geq 30.00\ kg/m^2$) makes the interpretation simpler and clinically relevant. However, categorization of a continuous variable has several drawbacks including problems with defining cut-point(s).

Categorisation of continuous variables is known to be problematic because it assumes everyone above or below the cut-point is equal, and thus fails to consider the within-category information (Naggara et al. 2011). Yet, the relative risk of pain and OA is likely to vary considerably according to BMI. It is also difficult to make comparisons between studies that use different cut-points. Efficiency is lost due to categorizing of a continuous variable and this loss increases further when one attempts to take into account confounding factors (Selvin 2004). The decision was made to treat BMI as a continuous variable and to assume the relationship between BMI and the dependent variable was linear in the logit. To allow comparison with the results of previous studies within the literature, the covariate BMI was also categorised into under / normal weight (< 25.00 kg/m^2), overweight ($\underline{\geq}$ 25.00 < 30.00), and obese ($\underline{\geq}$ 30.00 kg/m^2).

2.2.11.11.4 Previous Significant Injury

GB Olympians were dichotomized into those with a history of a significant joint injury (i.e. that caused pain for most days during a one-month period and for which the individual consulted a medical professional or a health provider such as a general practitioner), and those who were injury free according to the specific joint under investigation. For example, a history of a significant knee injury was included in the analysis of knee pain but excluded in the analysis of hip pain. The most severe joint was selected in cases were pain or OA was reported bilaterally in the hip and/or knee. Injury status was matched to

the index limb and the status of an injured joint took preference over a non-injured limb. Statistical analysis was undertaken separately for injury, along with pain and OA at the knee, hip and lumbar spine.

2.2.11.11.5 Occupational Physical Activity

The sporting discipline in which GB Olympians competed at the highest level was analysed in relation to the prevalence of pain and OA at specific joint sites. Where GB Olympians had competed in at least two disciplines at Olympic level, preference was given to the discipline in which the GB Olympian had spent the longest time competing. Sporting disciplines were categorised into: 1) impact sports, and 2) non-impact sports, a method previously used by Tveit et al (2012). Impact sports refer to contact sports and non-impact refers to non-contact sports. Impact sports included: basketball, football, handball, hockey, judo, taekwondo, karate, fencing and water polo. Non-impact sports included athletics (track and field), archery, badminton, biathlon, short track speed skating, speed skating, canoeing / kayak, cycling, gymnastics, shooting, rowing, sailing, table tennis, tennis, volleyball, weightlifting, aquatics (diving, swimming, and synchronised swimming), skiing (alpine skiing, cross country skiing, snowboarding, freestyle skiing), bobsleigh, equestrian, luge, and skeleton.

Sporting disciplines were also recoded into: 1) weight-bearing loading-sports, and 2) non-weight-bearing loading-sports. Weight bearing sports were defined by weight bearing with torsional loading. Archery and

shooting disciplines were therefore classified as non-weight bearing sports together with canoeing / kayak, cycling, equestrian, rowing, luge, aquatics (diving, water polo, swimming, and synchronised swimming). Weight-bearing sports included: athletics (track and field), skiing (alpine skiing, cross country skiing, snowboarding, freestyle skiing), badminton, basketball, biathlon, bobsleigh, boxing, fencing, skating (figure skating, short track speed skating, and speed skating), football, gymnastics, handball, hockey, judo, taekwondo, sailing, skeleton, table tennis, volleyball, weightlifting, karate, wrestling, and ice hockey.

2.2.11.11.6 Biomechanical Alignment

The visual classification of knee angulation consisted of GB Olympians classifying each lower limb according to whether the right and left limb was visually aligned (normal), bow-legged (varus), or knock-kneed (valgus). Knee angulation was matched to the index knee for pain and OA analysis. Varus or valgus alignment was selected in cases were pain or OA was reported bilaterally. Current and past knee angulation during the athlete's 20's was analysed separately in relation to pain and OA at the hip, knee, and lumbar spine.

2.2.11.11.7 Generalised Joint Hypermobility

Joint flexibility was determined by self-examination using line drawings of nine genetically determined sites from the 9-point Beighton score (see Chapter 1: Table 2). A current Beighton score was obtained by adding together the results from questions 7.5a, 7.6a, 7.7a, 7.8a, 7.9a,

and 7.10a in section seven of the Olympian questionnaire (see Appendix G). The results from questions 7.5b, 7.6b, 7.7b, 7.8b, 7.9b, and 7.10b were added together to estimate a Beighton score for GB Olympians in their 20's retrospectively. A cut-off threshold of $\geq$ 4/9 on the modified Beighton 9-point scoring system was used to denote generalised joint hypermobility (GJH), as recommended by the British Society of Rheumatology (Remvig et al. 2007).Those who did not complete all parts of the self-examination joint hypermobility score were labelled as missing cases and excluded from the data analysis, as it was unknown whether they had GJH or not. Data was dichotomized into two groups: 1) those with GJH, and 2) those without. Odd ratios were calculated using logistic regression. The statistical analysis was repeated to examine the relationship between GJH and self-reported, physician-diagnosed OA.

2.2.11.11.8 Limb Dominance

Limb dominance was categorised in relation to the GB Olympians athletics sports career into: 1) upper right limb dominance, or 2) upper left limb dominance, or 3) equally proficient upper limbs, and 4) right lower limb dominance, or 5) left lower limb dominance, or 6) equally proficient lower limbs. Only the lower limb status was assessed in relation to pain and OA at the hip, knee, and lumbar spine. The upper limb status was excluded from the logistic regression analysis because inter-class correlations indicated a high correlation (.7) existed between the dominance in the lower and upper limbs.

2.2.11.11.9 Genetics / Heberden's and Bouchard's Nodes

The presence of interphalangeal (IP) nodes was determined by self-reported visual inspection using hand diagrams, previously used by Ingham (2010). Finger nodes were initially defined by a method previously described by Zhang et al. (2008), whereby nodal changes were defined by Heberden's and/or Bouchard's nodes in at least 2 rays of each hand. However, there were insufficient cases of Heberden's and Bouchard's nodes with knee pain after exclusion of missing data for each covariate in the logistic regression model. Therefore, Heberden and Bouchard's nodes were subsequently redefined as one node per hand.

2.2.11.11.10 Index to Ring Finger Ratio

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). The right hand was selected as the single index hand for statistical analysis, unless there was missing data or amputation of the right ring or index fingers. The basis for selecting the right hand is based on fewer missing cases and the findings of previous studies, which have shown that the index to ring finger ratio does not associate with handedness or age (Robertson et al. 2008). The index to ring finger ratio has also been shown to have radiographic symmetry with only very small differences between the right and left hands (Zhang et al. 2008; Paul et al. 2006).

2.2.11.11.11 Comorbidities

Data was dichotomized 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 comorbidities. The relationship between comorbidities and OA was investigated by substituting joint pain with self-reported, physician-diagnosed OA. Odd ratios were calculated using logistic regression analysis. A separate chi-square test for independence was performed to examine the relationship between individual co-morbidities and pain or OA. Data was dichotomized into five individual comorbidities, based on those suffering with a specific condition including: cancer, lung disease, diabetes, cardiac disease, or stroke.

2.2.11.11.12 Widespread Body Pain

Three types of bodily pain were determined from the pain manikin. First, the individual defined areas of pain were recorded separately using the templates in Figure 3. Second, the number of areas in which pain was recorded was totalled, and responses were categorised based on previous research by Thomas et al. (2004). The total scores were split into five groups: 1) no body pain, 2) pain in 1-3 areas, 3) pain in 4-6 areas, 4) pain 7-11 areas, and 5) pain 12-44 areas. Third, the definition of chronic widespread pain (CWP) was identified according to the ACR classification described by Wolfe et al (1990).

Widespread pain was identified when all the following are present: 1) pain on the left side of the body; 2) pain on the right side of the body; 3) pain above the waist; 4) pain below the waist; and 5) axial skeleton pain referred to as cervical spine, anterior chest or thoracic spine or lower back had to also be present (Wolfe et al. 1990). Widespread pain was recorded if an individual had axial pain plus pain in at least two sections of each of two contralateral quadrants of the body, a method previously recommended by Thomas et al. (2004). Thus, widespread pain was calculated from the 44 different regions of the body pain manikin, with axial pain and quadrant pain defined by the coding shown in Table 13.

Table 13: Identification of Widespread Pain

Body Area	Region Numbers
Axial	2 or 23 or 13 or 32 or 33
Upper left arm and shoulder	3 or 4 or 5 or 6 or 11 or 28 or 29 or 30 or 31 or 33
Upper right arm and shoulder	7 or 8 or 9 or 10 or 12 or 24 or 25 or 26 or 27 or 32
Lower left leg	14 or 14a or 15 or 16 or 17 or 39 or 40 or 41 or 42
Lower right leg	18 or 18a or 19 or 20 or 21 or 35 or 36 or 37 or 38

The statistical techniques chi-square test of independence and logistic regression were used to determine any other association between CWP

and knee pain, and other body pain and knee pain. The knee pain sites from the pain manikin (regions 15, 19, 36 and 40) were excluded from the final analysis for CWP to allow for a comparison to be made between knee pain and other chronic painful sites. This process was not repeated for other joint sites because the regions of CWP overlapped with the region of neck pain, hip pain, and the lumbar spine.

2.2.11.11.13 Physical and Mental Wellbeing

The 12-item Short Form Health Survey (version one) required GB Olympians to rate their agreement or disagreement according to 12 statements using a 2-point, 3-point, 5-point and 6-point Likert Scale. The SF-12 Health Survey is a short version of the SF-36 Health Survey - a generic measure of quality of life. The SF-12 uses just 12 of the 36 questions of the SF-36. Both these survey instruments measure the physical and mental wellbeing from the perspective of the individual completing the survey. Both measures contain the following eight subscales: 1) physical functioning, 2) physical role function, 3) bodily pain, 4) general health, 5) mental health, 6) emotional role functioning, 7) social functioning, and 8) vitality subscales.

Each of the eight different subscales was calculated based on the responses to the individual items in the respective health survey. Table 14 illustrates the relevance of each question to the items of the eight subscales for the SF-36 and SF-12. The SF-12 Health Survey uses two items per scale to estimate four of the health concepts (physical

functioning, physical role, emotional role, and mental health), and the remaining four scales (bodily pain, general health, vitality, and social functioning) are represented by a single item. All 12-items were used to calculate the Physical Component Score (PCS-12) and the Mental Component Score (MCS-12).

Table 14: Components of the Short Form 12 & 36 Health Surveys

Domains	SF-36 Questions	SF-12 Question
Physical functioning (PF)	3, 4, 5, 6, 7, 8, 9, 10, 11, 12	2 (2 items)
Physical role function (PR)	13, 14, 15, 16	3 (2 items)
Bodily pain (BP)	21, 22	5 (1 item)
General health (GH)	1, 33, 34, 35, 36	1 (1 item)
Mental health (MH)	24, 25, 26, 28, 30	6 (2 items)
Emotional role functioning (EF)	17, 18, 19	4 (2 items)
Social functioning (SF)	20, 32	7 (1 item)
Vitality (VI)	23, 27, 29, 31	6 (1 item)

Scoring the SF-12 PCS-12 and MCS-12 scales involved four steps described in greater detail by Ware et al. (2002). The first step required four-items to be reversed-scored because higher pre-coded item values for these items indicate a poorer health state. The four-items that were reversed scored are: GH1 (item 1), BP2 (item 8), MH3 (item 9), and

VT2 (item 10). The second step involved creating indicator variables for all but one of the response choice categories for each of the 12 questions. A ‘one’ was assigned to the choice category chosen, and a ‘zero’ was assigned to those choice categories that were not chosen. An indicator variable was not created for the highest health state for each of the 12 questions. From a total possible of 47 response choice categories among the 12-items in the SF-12, only 35 indicator variables were created.

The third step involved applying a scoring algorithm derived from the data of a general health population survey in the United States (See Appendix Q). The PCS-12 and MCS-12 were calculated by multiplying each indicator variable by its respective physical or mental regression weight, and summing the 35 products. Step 4 involved transforming each summary scales score to the norm-based standardisation of scale scores. This was accomplished by adding the respective constant to the sum of the 35 products for the PCS-12 and MCS-12. There are two options for standardising both summary scales. The second option - the 1998 constant, standardises PCS-12 and MCS-12 to have a mean of 50, and standard deviation of 10, based on the 1998 general US population.

3.0 DEVELOPMENT AND VALIDATION OF A SELF-REPORTED JOINT HYPERMOBILITY INSTRUMENT

3.1 Background

The Beighton 9-point scoring system – also referred to as the modified or revised Beighton score – is widely accepted as the method used to define generalised joint hypermobility (GJH) (Pacey et al. 2014). Although the modified Beighton score (see Chapter 1, Table 2, p.25) is relatively quick, safe and simple to use, it requires a trained observer to conduct the assessment. The impracticalities and comparative expense of carrying out an assessment is an obstacle in many large epidemiological studies. A practical alternative is the use of self-reported line drawings, based on the modified Beighton score (Beighton et al. 1973). Simple line drawings have been used successfully in self-reported questionnaires for reporting bodily pain (Ingham 2010) and recording physical traits, such as knee mal-alignment and foot rotation (Ingham et al. 2010), Heberden's and Bouchard's nodes (O'Reilly et al. 1999), and hallux valgus (Garrow et al. 2001).

The purpose of this study was to develop, and validate against clinical assessment, an original, self-reported electronic version of the Beighton score; a version that may be suitable for large epidemiological studies.

3.2 Methods

3.2.1 Development of the Self-Reported Joint Hypermobility Instrument

Five novel line drawings were created to depict the 9-point Beighton score criteria. All five items were created with two depictions, which represented a positive and a negative test for GJH. When four of the five items (elbow extension, knee extension, little finger extension, and trunk flexion) were reconfigured following early pilot testing and consultation with a Patient Public Involvement (PPI) panel, each then included three intervals. The remaining item (thumb opposition) remained unchanged and consists of two intervals. Each item in the self-reported joint hypermobility instrument is accompanied by a set of instructions which communicates to the participant how the instrument should be used. Those completing the self-reported instrument are requested to record their current self-reported Beighton score, and if they are over 30 years of age, to estimate which line drawings best illustrate their joint angles in their 20's.

The rationale for incorporating a historic Beighton score is to attempt to account for the biomechanical stresses caused by hypermobility in early life. Historic self-report scores have previously been used to measure foot rotation and knee alignment (Ingham et al. 2010). The process of developing the self-report hypermobility novel line drawings are described below.

3.2.1.1 Item One - Trunk Flexion

The first novel line drawing was created to depict forward flexion of the trunk, with the knees straight, so that the palms of the hands rest flat on the floor (see Figure 4). The line drawing consists of three intervals, with varying degrees of trunk flexion, and is dichotomized into three outcomes: a) unable to touch the floor, b) fingertips touching the floor and c) palms of the hands rest flat on the floor. A positive test is denoted by category ‘C’, with the former two categories ‘A’ and ‘B’ indicating a negative test result. A modified sit-and-reach version of the test was developed to enable those with reduced standing balance to perform the test. The modified version is dichotomized into three outcomes: d) can’t touch toes, e) can touch toes, and f) can reach over toes (see Figure 1). Category ‘D’ and ‘E’ denote a negative test result with category ‘F’ indicating a positive outcome.

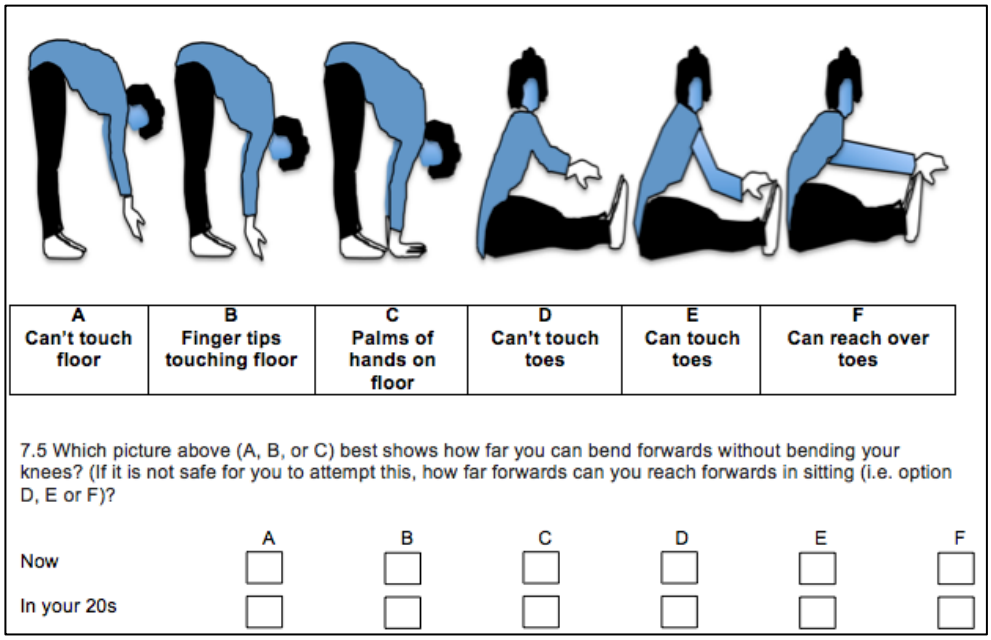


Figure 4: Trunk Flexion

3.2.1.2 Item Two - Knee Extension

The second line drawing was created to depict extension of the tibiofemoral joint beyond -10 degrees. From a lateral perspective, a straight aligned knee was initially drawn with two interval changes of eleven degrees either side to illustrate knee-flexion and knee-extension. During early pilot work, it was noted that participants experienced difficulty in distinguishing between knee-extension ROM of 0-10 degrees (a negative test result), and knee-extension ROM beyond -10 degrees (a positive test result). The intervals were adjusted to twenty degrees to enable participants to differentiate more clearly between a positive (A) and negative test (B or C). A red line was drawn on the knee line drawing and the subsequent line drawings (thumb, elbow, and little finger) to illustrate the angle at the joints more clearly (see Figure 5).

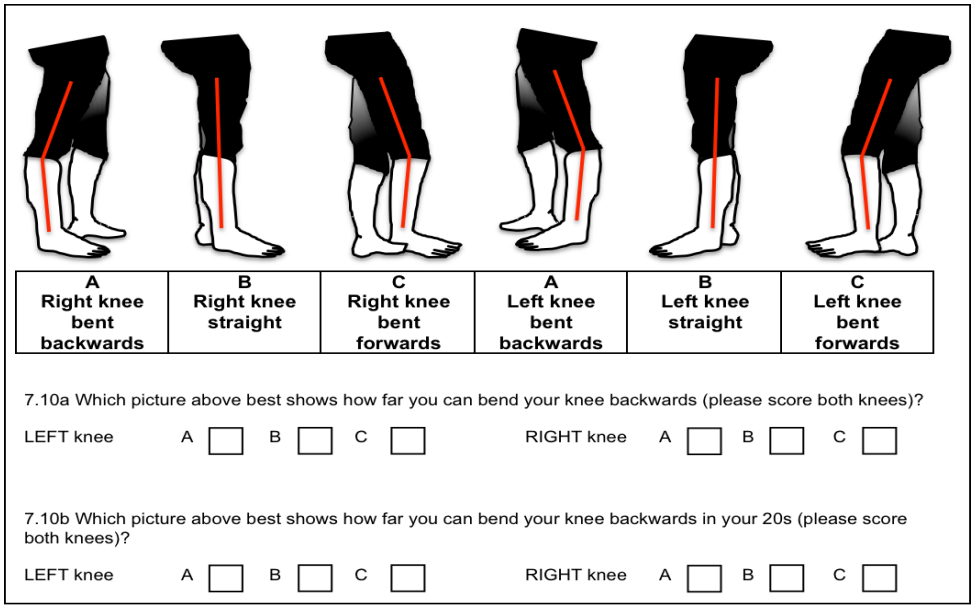


Figure 5: Knee Extension

3.2.1.3 Item Three - Thumb Opposition

The third line drawing was created to illustrate the ability to passively extend the thumb and flex the wrist, so that the distal phalanx of the thumb can touch the distal radial side of the adjacent forearm (see Figure 6). The line drawing consists of two intervals that depict a positive test (A: the thumb touches the forearm), and a negative test (B: the thumb is unable to touch the forearm).

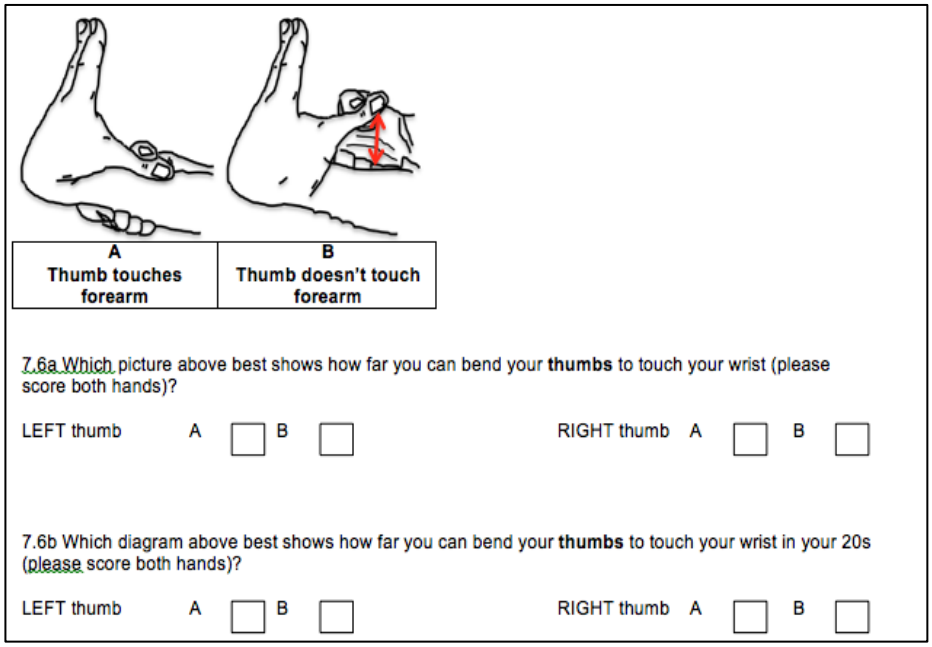


Figure 6: Thumb Opposition

3.2.1.4 Item Four - Elbow Extension

The fourth line drawing was created to illustrate the ability to extend the elbow joint beyond -10 degrees. A single line drawing was created with the elbow in a plane of 0 degrees of extension. Two further line drawings were created with 11 degrees intervals in either direction.

Following early pilot testing, these two intervals were subsequently increased to 15 degrees to help distinguish between them more clearly. Thus, the line drawing consists of three intervals with varying degrees of elbow flexion-extension and is dichotomized into three outcomes: a) elbow flexion, b) the elbow in a neutral plane, and c) elbow extension (see Figure 7). Categories ‘A’ and ‘B’ both indicate a negative test result, with category ‘C’ denoting a positive test for elbow joint hypermobility.

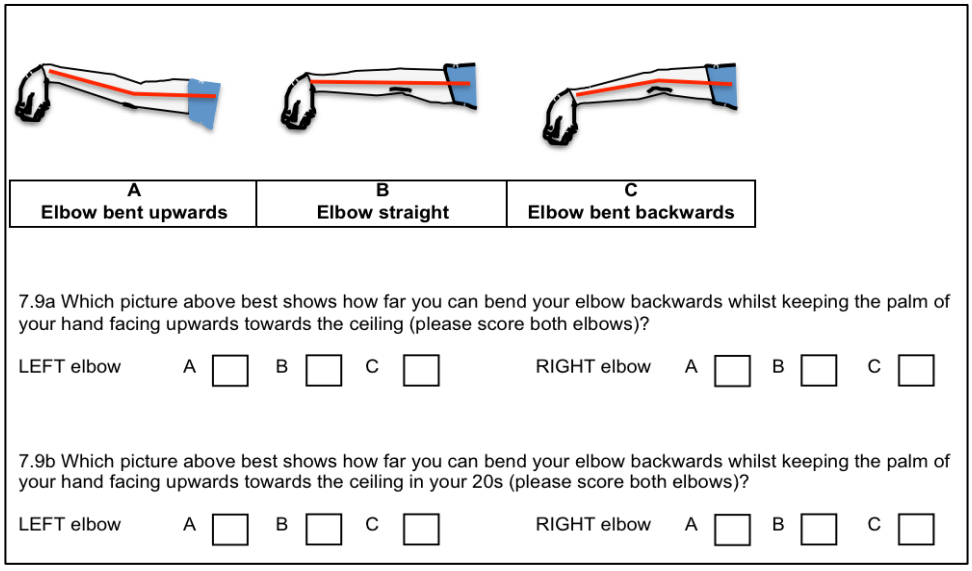


Figure 7: Elbow Extension

3.2.1.5 Item Five – Little Finger Extension

The fifth line drawing was designed to replicate passive extension of the 5th finger beyond 90 degrees. The line drawing consists of three intervals to depict: a) the 5th finger extending beyond 90 degrees, b) the 5th finger extending equal to 90 degrees, and c) the 5th finger extending less than 90 degrees (see Figure 8). Both categories ‘B’ and ‘C’ denote

a negative test result, with category ‘A’ indicating a positive test result for joint hypermobility of the little finger.

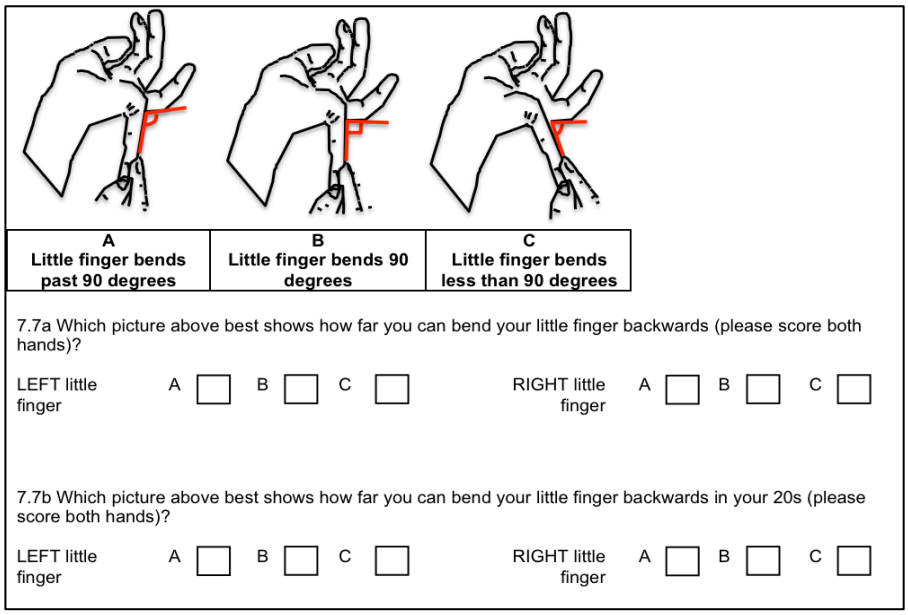


Figure 8: Little Finger Extension

3.2.2 Validation of the Novel Line Drawings

The development and validation of the self-reported joint hypermobility instrument formed part of the wider thesis which examined pain and self-reported, physician-diagnosed OA in GB Olympians. The study was approved by the Faculty of Medicine and Health Sciences (FMHS) Research Ethics Committee at the University of Nottingham. The study sample consisted of 50 staff members and undergraduate students recruited from the University. The sample size is considered sufficient to detect a moderate agreement of 0.4 when using Kappa statistics, based on a significance level of 0.05 and a power of 80% (Terwee et al. 2007). Participants were recruited between February 2014 and June 2014

using: a) a pilot study advertisement (Appendix L) posted in the School of Health at the University, and b) by asking for volunteers after giving three guest lectures in the School of Nursing at the named institution. All participants were issued with a copy of the participant information sheet (Appendix M) and provided informed, written consent (Appendix N).

3.2.2.1 Participant-Reproducibility (Intra-Rater Reliability)

Using the set of instructions that accompanied each of the novel line drawings, participants were requested to self-score their joint mobility. All the participants' received access to complete an electronic version of the self-reported joint hypermobility instrument. Each participant was then requested to complete the line drawings alone, to replicate how the instrument would work in practice. Each of the participants' were requested to record forward flexion of his or her trunk in standing, and then to repeat this in sitting. This investigated the validity of the modified trunk flexion test. Participants were requested to complete two self-examinations, a fortnight apart. This time interval was chosen to be long enough to prevent recall, and short enough to ensure that clinical change had not occurred. There was no self-reported change in health status between the distributions of the two self-report forms. The results of the previous assessment were not made available to the participants.

3.2.2.2 Participant-Observer Agreement (Inter-Rater Reliability)

All participants completed the two self-reported assessments online,

before attending a clinical assessment at the Queens Medical Centre in Nottingham. The clinical assessment observer completed the examiner-version of the self-reported joint hypermobility instrument using a mechanical goniometry assessment protocol (Appendix R) and a scoring card (Appendix S). So as to ensure that the observer was blinded to the results of the participants, the online data was downloaded only after the clinical assessments had taken place.

Goniometric measurements of the elbow, knee, first carpometacarpal and fifth metacarpophalangeal joints were performed according to guidelines described by Norkin and White (2009). Goniometric measurement of knee extension was shown to have an excellent intra-rater and inter-rater reliability (Brosseau et al. 2001; Youdas et al. 1993), and goniometric measurement of elbow extension has been shown to have excellent intra-rater reliability and inter-rater reliability (Chapleau et al. 2011). Trunk flexion was assessed using a modified fingertip-to-floor distance (FFD) measurement. The FFD has been shown to have excellent inter-test reliability of lumbar spine flexion (Robinson & Mengshoel 2014). A second observer, who was blinded to the participants' results, scored the self-reported joint hypermobility instrument using data from the observer's scorecard. The results of the trained assessor and those of the participants were compared to determine the level of participant-observer agreement, also referred to as inter-rater reliability.

3.2.2.3 Observer-Reproducibility (Intra-Rater Reliability)

The first assessment took place within two weeks of the participants having completed the second self-reported score. Each participant was requested to return one week later, to undergo a second clinical assessment. The purpose of this assessment was to ensure that the reference standard measurement (i.e. manual goniometry) was valid. One examiner executed the reference standard and a second examiner read and coded the participants' self-reported forms, using the data from the goniometry scorecards. Data from each item in the self-reported form was reduced by the second independent assessor to either a 'positive' or 'negative' result for joint hypermobility. The results of the previous mechanical goniometry assessment were not made available to the assessor, or to the participants.

3.3 Statistical Analysis

Validity was determined by calculating sensitivity, specificity, and likelihood ratios from standard two-by-two tables. Sensitivity refers to the proportion of true positives that are correctly identified by the test, whereas specificity refers to the proportion of true negatives that are correctly identified (Altman & Bland 1994). The optimum self-reported measure i.e. a test that is 100% sensitive and specific (Ingham et al. 2010) would have a value of one for sensitivity and specificity. Likelihood ratios are an alternative method for summarizing the diagnostic accuracy of a test. A likelihood ratio greater than one indicates that the test result is associated with the presence of the

disease, whereas a likelihood ratio of less than one indicates that the test result is associated with the absence of the disease. Likelihood ratios above 10 and below 0.1 were interpreted as strong evidence to rule diagnoses in or out, respectively (Deeks & Altman 2004).

The reliability of the self-reported joint hypermobility instrument was determined by repeated measures within participants, and between the participants and the observer - the reference standard. Reproducibility was calculated using Kappa agreement statistics (k) for each item of the self-reported form separately, and for the sum of the total scores. The strength of agreement was interpreted as < 0 = poor, 0.01-0.20 = slight, 0.21-0.40 = fair**,** 0.41-0.60 = moderate, 0.61-0.80 = substantial, and 0.81-1 = almost perfect (Landis & Kock 1977). Statistical analysis was performed using SPSS (SPSS for Windows Version 12.0, Chicago, III).

3.4 Results

3.4.1 Participant Demographics

Fifty participants provided data for the self-reported joint hypermobility score reliability and validity assessment. The age of the participants ranged from 20 to 66, with a median age of 49 years. Twenty-two of the participants were male. Three participants were Asian and 47 were White British. The prevalence of GJH using the reference standard (i.e. clinical assessment) was 14% defined by a cut-off threshold of $\geq$ 4/9 on the modified Beighton scale. A total of 78.6% of females were non-hypermobile and 21.4% were hypermobile. This compared with 95.5%

of males who were non-hypermobile and 4.5% who were classed as hypermobile. During this validation, the full series of each line drawing depicting hypermobility and non-hypermobility was assessed. Four additional participants were excluded from the data analysis because of failure to attend for the follow-up assessment. There was no missing data from the 50 participants who were included in the statistical analysis.

3.4.2 Validation of the Self-Reported Joint Hypermobility Instrument

The instrument appeared to be highly sensitive and specific for trunk flexion in standing and in sitting, extension of the right and left knee, and opposition of the left and right thumb (see Table 15). The self-reported instrument also appeared to provide a valid assessment of extension of the right and left elbow, and extension of the right and left fifth finger. Overall values of sensitivity, specificity and likelihood ratios can be seen in Table 15. The sum of each item in the self-reported joint hypermobility instrument produced a self-reported modified Beighton score that appeared to be highly sensitive, specific, and comparable to expert clinical assessment.

Table 15: Validity Data for the Self-Reported Line Drawings

Self-Reported Hypermobility			Sensitivity (95% CI)	Specificity (95% CI)	Likelihood ratio (95% CI)
Item-1	Lumbar Spine	In standing	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	Infinity
Item-1	Lumbar Spine	In sitting	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	Infinity
Item-2	Knee	Right	1.00 (1.00, 1.00)	0.97 (0.94, 1.01)	38.5 (9.81, 151.18)
Item-3		Left	0.91 (0.74, 1.08)	0.99 (0.97, 1.01)	80.91 (11.42, 573.18)
Item-4	Thumb	Right	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	Infinity
Item-5		Left	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	Infinity
Item-6	Elbow	Right	0.68 (0.51, 0.85)	1.00	Infinity
Item-7		Left	0.90 (0.79, 1.01)	0.99 (0.96, 1.01)	63 (8.97, 442.62)
Item-8	Fifth Finger	Right	0.67 (0.43, 0.91)	1.00	Infinity
Item-9		Left	0.60 (0.30, 0.90)	1.00	Infinity
	Overall		0.87 (0.82, 0.92)	1.00 (0.99, 1.00)	158.96 (59.72, 423.14)

CI – Confidence Interval

Table 16: Reproducibility and Agreement between the Self-Reported Line Drawings and the Clinical Assessment

			Reproducibility		Agreement
Self-Reported Hypermobility			Participant Intra k (95% CI)	Observer Intra k (95% CI)	Participant Observer Inter k (95% CI)
Item-1	Lumbar Spine	In standing	1.00	1.00	1.00
Item-1	Lumbar Spine	In sitting	1.00	1.00	1.00
Item-2	Knee	Right	0.88 (0.73, 1.00)	1.00	0.95 (0.87, 1.02)
Item-3		Left	0.88 (0.86, 1.11)	0.88 (0.86, 1.11)	0.90 (0.76, 1.04)
Item-4	Thumb	Right	1.00	1.00	1.00
Item-5		Left	1.00	1.00	1.00
Item-6	Elbow	Right	0.94 (0.81, 1.06)	0.95 (0.84, 1.05)	0.75 (0.60, 0.90)
Item-7		Left	0.95 (0.84, 1.05)	0.95 (0.85, 1.05)	0.90 (0.81, 1.00)
Item-8	Fifth Finger	Right	0.88 (0.64, 1.11)	1.00	0.77 (0.59, 0.96)
Item-9		Left	0.79 (0.30, 1.19)	0.88 (0.64, 1.11)	0.73 (0.48, 0.98)
	Beighton Score		0.91 (0.74, 1.08)	1.00	0.96 (0.87, 1.04)

$\underline{<}$ 0 = poor agreement, 0.01-0.20 = slight agreement, 0.21-0.40 = fair agreement, 0.41-0.60 = moderate agreement, 0.61-0.80 = substantial agreement, 0.81-1.00 = almost perfect agreement (Landis & Kock 1977).

3.4.3 Reliability of the Self-Reported Joint Hypermobility Instrument

3.4.3.1 Trunk Flexion

The intra-rater and inter-rater reliability scores of the self-reported joint hypermobility instrument are shown in Table 16. Participant-reproducibility measured the reliability of reproducing a concordant Beighton score on two separate occasions, using the self-report hypermobility instrument. Observer-reproducibility examined the reliability of reproducing an equivalent Beighton score with the use of clinical assessments, whereas the participant-observer agreement compared the participants' self-report score with the scores from the standard reference – the observer clinical assessment. The participant-reproducibility (intra-rater reliability) and observer-reproducibility for trunk flexion was excellent (k 1.00; 95% CI, 1.00-1.00), with 100% of the participants and the observers being able to reproduce exactly the results they had reported in the first assessment. The kappa score for the participant-observer agreement (inter-rater reliability) was excellent (k 1.00; 95% CI, 1.00-1.00), with 100% of the participants' results replicated by the observer. The participant-reproducibility, observer-reproducibility, and participant-observer agreement were identical for trunk flexion in sitting (k 1.00; 95% CI, 1.00-1.00).

3.4.3.2 Knee Extension Hypermobility

The participant reproducibility for the knee line drawings were excellent for the left knee (k 0.88, 95% CI, 0.86-1.11) and the right knee (k 0.88;

95% CI, 0.73-1.00). The observer reproducibility was perfect for the right knee (k 1.00; 95% CI, 1.00-1.00) and identical to the participant reproducibility for the left knee (k 0.88; 95% CI, 0.86-1.11). The participant-observer agreement was excellent for the right knee (k 0.95; 95% CI, 0.87-1.02) and slightly lower but still excellent for the left knee (k 0.90; 95% CI, 0.76-1.04).

3.4.3.3 Thumb Opposition

The participant-reproducibility and the observer-reproducibility were found to be identical and excellent for the right and left thumb line drawings (k 1.00; 95% CI, 1.00-1.00), with 100% of the participants and observers being able to reproduce exactly the results reported in the first assessment. The kappa score for participant-observer agreement was excellent for the right thumb (k 1.00; 95% CI, 1.00-1.00) and left thumb line drawing (k 1.00; 95% CI, 1.00-1.00), with 100% agreement between the results of the participants and those of the observers.

3.4.3.4 Elbow Extension

The kappa score for the participant-reproducibility was excellent for the right elbow (k 0.94; 95% CI, 0.81-1.06) and the left elbow (k 0.95; 95% CI, 0.84-1.05). The kappa score for the observer-reproducibility was excellent for the left elbow (k 0.95; 95% CI, 0.85-1.05) and identical for the right elbow (k 0.95; 95% CI, 0.84-1.05), albeit with a slightly wider confidence interval. The participant-observer agreement was excellent for the left elbow (k 0.90; 95% CI, 0.81-1.00). Despite the lower score,

there was still substantial agreement for the right elbow (k 0.75; 95% CI, 0.60-0.90).

3.4.3.5 Little Finger Extension

The kappa score for participant-reproducibility was excellent for the right little finger (k 0.88; 95% CI, 0.64-1.11), with substantial agreement for the left little finger (k 0.79; 95% CI, 0.30-1.19). The observer-reproducibility was perfect for the right little finger and excellent for the left little finger (k 0.88; 95% CI, 0.64-1.11). There was substantial agreement for the observer-participant reproducibility for the right little finger (k 0.77; 95% CI, 0.59-0.96) and the left little finger (k 0.73; 95% CI, 0.48-0.98).

3.4.3.6 Overall Beighton Score

The kappa score was calculated for the aggregate scores for each of the items in the self-reported instrument. The kappa score for the observer-reproducibility between the two clinical assessments demonstrated perfect agreement (k 1.00; 95% CI, 1.00-1.00). Compared with the observer-reproducibility, participant-reproducibility was lower but there was still excellent agreement (k 0.91; 95% CI, 0.74-1.08). The participant-observer agreement between the two self-reported assessments was excellent (k 0.96; 95% CI, 0.87-1.04).

3.5 Discussion

This study details the development and validation of a novel, electronic self-reported instrument for examining joint hypermobility. When assessing each item in the self-reported joint hypermobility instrument and also for the sum of the total scores, supporting their use in self-reported questionnaires, validity and reliability was high. In this study population, the self-reported joint hypermobility instrument appears to be sensitive, specific, and reliable. Importantly, there is substantial agreement with the observer clinical assessments. To the author's knowledge, this is the first self-reporting electronic line-drawing instrument for examining generalised joint hypermobility (GJH). Previous studies have used clinical examination (Tobias et al. 2013; Konopinski et al. 2012), which is time consuming, costly and impractical for epidemiological studies of significant size. The self-reported joint hypermobility instrument used in this study appears to provide strong agreement with clinical assessment - the reference standard used in clinical practice. It is easy to use and would be particularly suited to large epidemiological studies using questionnaires, due to the lower cost and reduced burden of administration.

There are several limitations to this study. Firstly, the sample is not a random sample and limits the ability to generalise the findings to the wider population. Secondly, the reference standard for determining validity and reliability of the self-reported joint hypermobility instrument was an observer's clinical assessment using manual goniometry rather

than radiographic measurement. Thirdly, imaging would be required for more accurate measurement of joint motion. However, imaging is less accessible and impractical for use in many epidemiological studies.

The novel line drawings were included in the Olympian questionnaire that was distributed to 2742 GB Olympians living in the UK and overseas. The results from the first application of this self-reported hypermobility instrument are shown in chapter six in an analysis which examines the individual risk factors associated with the onset of pain and self-reported physician-diagnosed OA in Great Britain's Olympians.

Overall, the present study findings show that the novel, self-reporting instrument is comparable to expert clinical assessment and has a practical use in future large epidemiological studies.

4.0 RECRUITMENT

4.1 The Great Britain's Olympian Study

The Olympian questionnaire was distributed to 2742 of the 2883 GB Olympians registered on the British Olympic Associations (BOA) Olympian database. A total of 141 athletes were excluded from recruitment because they either had no contactable address on the BOA Olympian database (*n* = 119), they were medically unsuitable to take part as a result of cognitive impairment (*n* = 13), or they were deceased (*n* = 9). The response rate was 26%, with 714 returns achieved between the 22nd of May 2014 and the 31st of January 2015 (see Figure 9). The breakdown of recruitment is subdivided into two phases (see Figure 10).

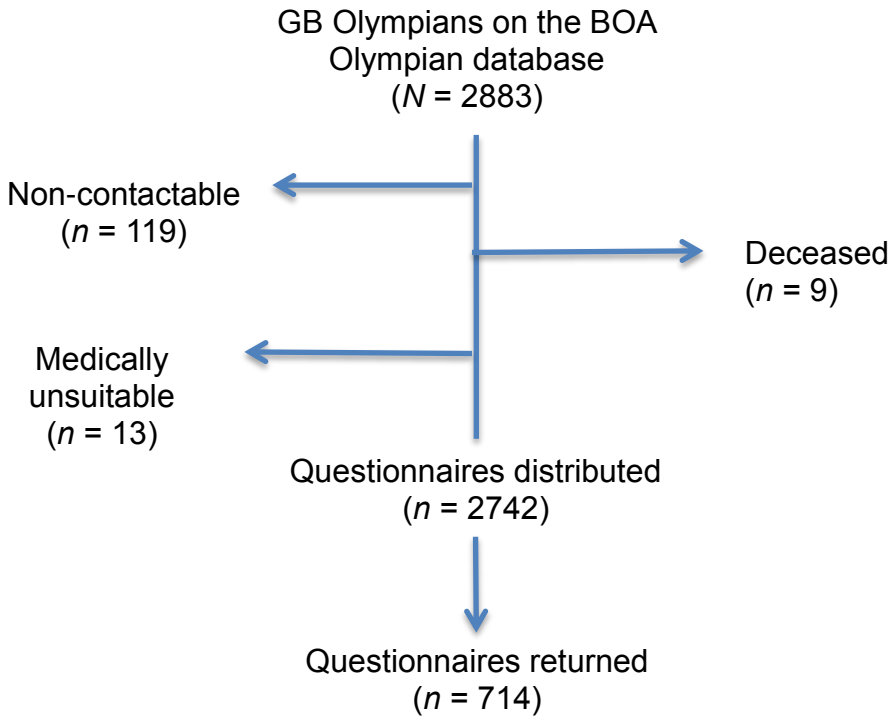


Figure 9: Summary of Recruitment

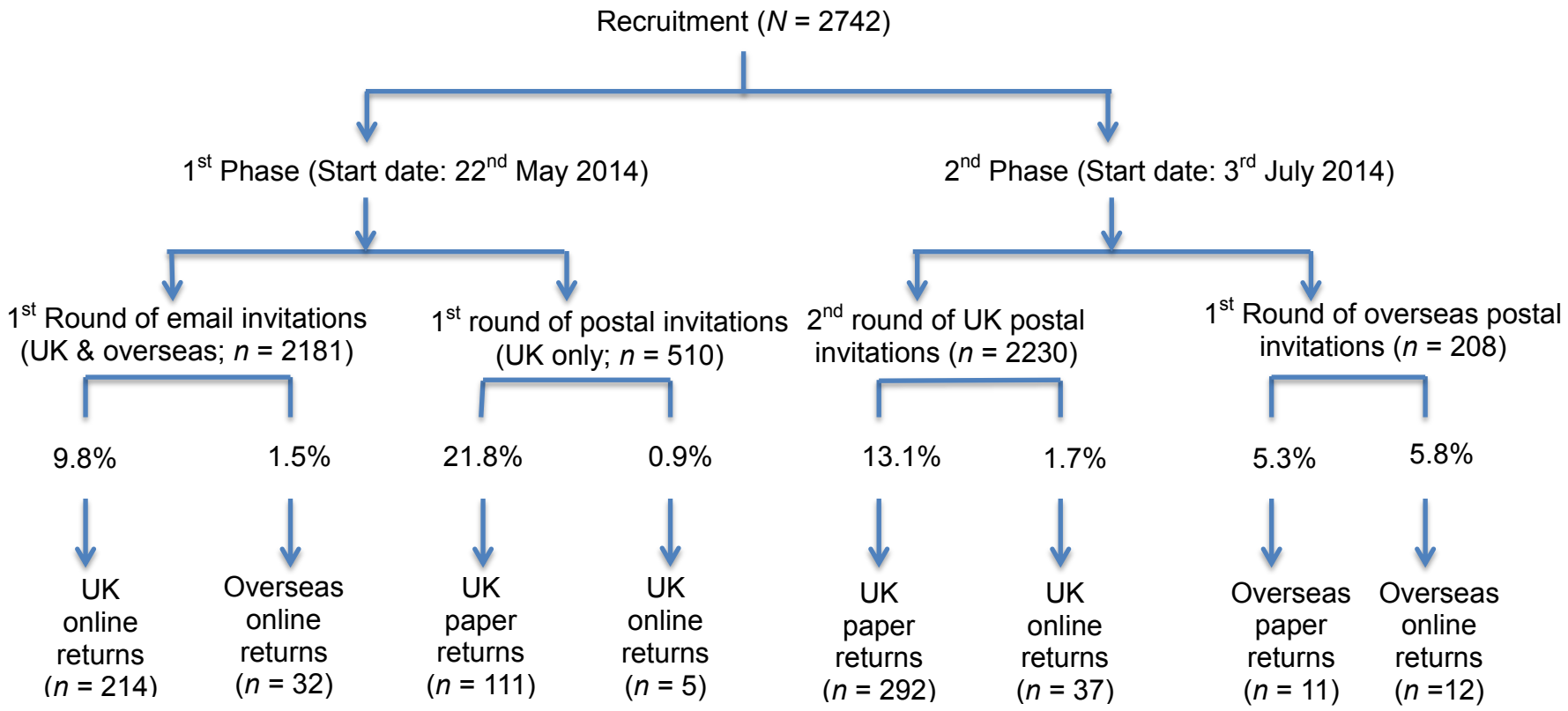


Figure 10: Flowchart of Breakdown of Recruitment

4.1.1 Breakdown of Recruitment

4.1.1.1 First Phase

The first phase of recruitment involved distributing invitations to complete the Olympian questionnaire to 2691 of the 2742 GB Olympians who were eligible for recruitment. Fifty-one GB Olympians who were eligible for recruitment were excluded at this time point because they resided outside of the UK and they had no active email address on the BOA Olympian database. During phase one of recruitment, invitations to complete the Olympian questionnaire were only distributed by email (*n* = 2181) or the postal service (*n* = 510) to UK addresses. The invitations distributed by email were sent to 1992 GB Olympians living in the UK and 189 GB Olympians residing in non-UK countries. In total, there was a response rate of 13.4%, with 362 returns from the 2691 GB Olympians contacted. Of the 13.4% return rate, 9.1% (*n* = 246 / 2,691) and 4.3% (*n* = 116 / 2,691) were achieved through the distribution of invitations by email and by post.

The actual return rate per the number of invitations distributed was significantly higher for postal invitations at 22.7% (*n* = 116 / 510) compared to 11.3% (*n* = 246 / 2181) from those invitations distributed via email. Of the 22.7% who replied to the postal invitation, 21.8% (*n* = 111) completed and returned a postal questionnaire and 0.9% (*n* = 5) alternatively submitted the online questionnaire. Of the 11.3% who replied to the email invitation, 9.8% (*n* = 214) were from GB Olympians residing in the UK and

1.5% (*n* = 32) of the replies were from GB Olympians living outside of the UK. The actual return rate per the number of GB Olympians contacted in the UK was 13.2% (*n* = 330 / 2502) compared to 16.9% (*n* = 32 / 189) for those living outside of the UK.

4.1.1.2 Second Phase

The second phase of recruitment involved distributing a paper copy of the Olympian questionnaire to all GB Olympians who had not returned the questionnaire from the first phase of recruitment. On the 4th of July and the 12th August in 2014, paper copies of the questionnaire were distributed to GB Olympians residing in the UK (*n* = 2230) and non-UK countries (*n* = 208) respectively. The overall response rate from the postal invitations sent to GB Olympians living in the UK was 14.8% (*n* = 329 / 2230). Of this 14.8%, 13.1% (*n* = 292 / 2230) returned a paper copy of the questionnaire and 1.7% (*n* = 27 / 2230) alternatively submitted the online version of the questionnaire. The overall response rate from the postal invitations to GB Olympians residing outside of the UK was 11.1% (*n* = 23 / 208). Of this 11.1%, 5.3% (*n* = 11 / 208) returned the paper questionnaire and 5.8% (*n* = 12 / 208) replied using the online questionnaire. The total number of paper replies from GB Olympians residing outside of the UK was 5.3% (*n* = 11 / 208). A total of 55 GB Olympians were recruited from outside of the host country where the mail out took place (see Figure 11). Overall, the return

rate from phase two of recruitment was 14.4% (*n* = 352 / 2438) compared to 13.4% (*n* = 362 / 2691) achieved from the first phase.

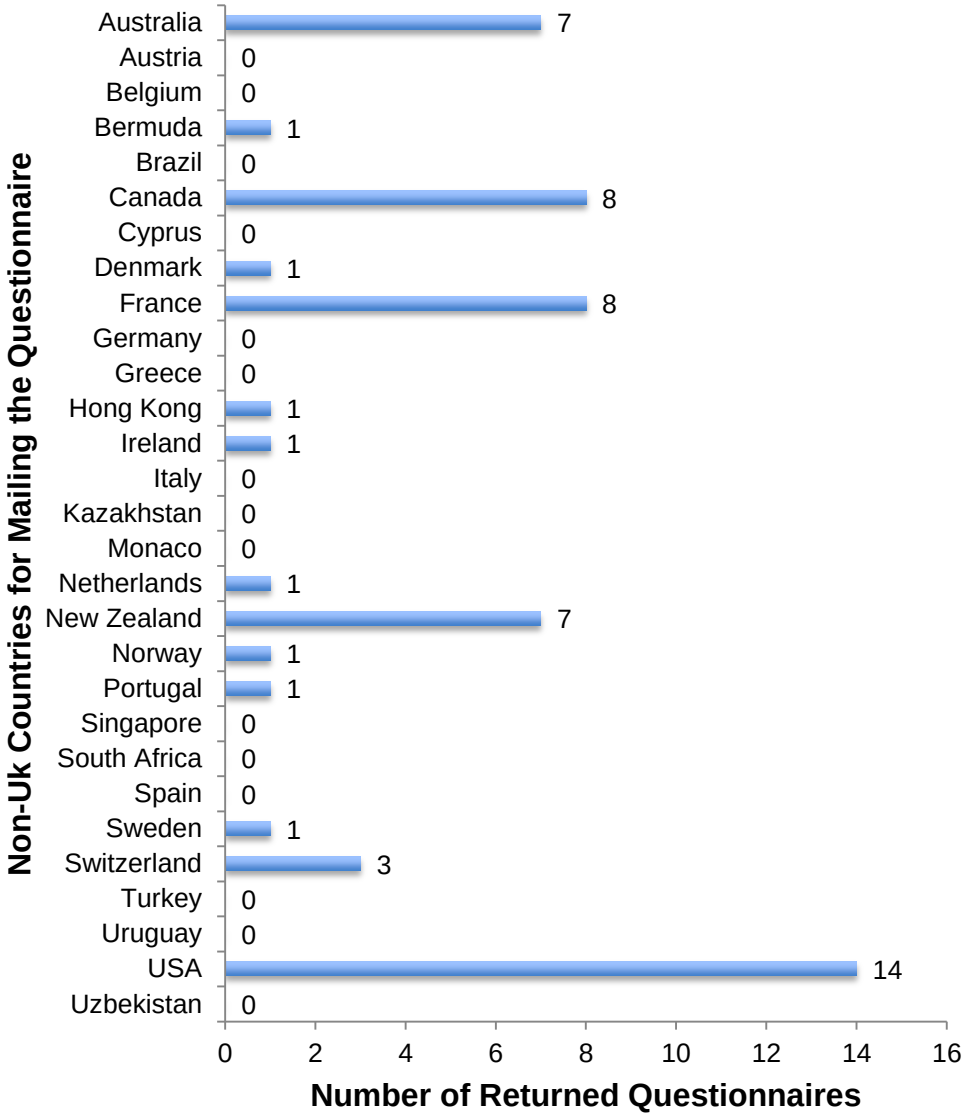


Figure 11: Response Rate by the Number of Returns from Non-UK Countries

4.1.2 Demographics

4.1.2.1 Age

The age of the GB Olympians recruited ranged from 19 to 97 years, with a mean age of 58.76 ± 16.79 years. The questionnaire response rate was greater amongst the older athletes (see Figure 12). Approximately, 38% (*n* = 493) of those aged over 50 years returned a questionnaire, compared to 19% (*n* = 112) of GB Olympians aged between 40-50 years, and 13% (*n* = 109) from those athletes aged less than 40 years.

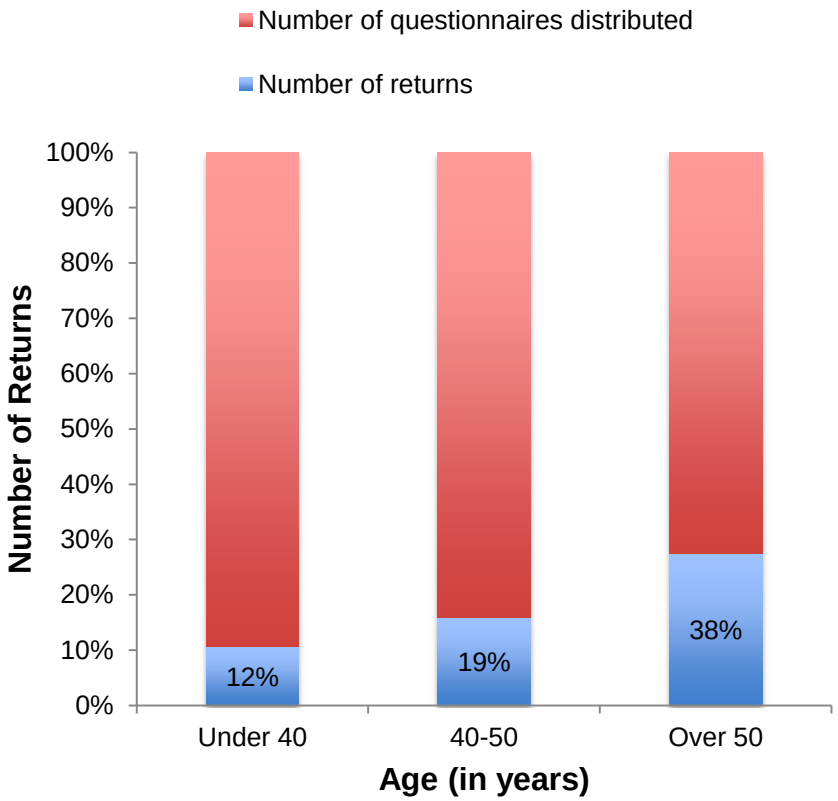


Figure 12: Response Rate by Age and Number of Returns

4.1.2.2 Gender

Fifty-seven per cent of those recruited were male (*n* = 405) and 43% were female (*n* = 309). The age of male GB Olympians recruited ranged from 22 to 97 years, with a mean age of 63.00 ± 16.30 years. The age range of female GB Olympians recruited ranged from 19 to 93 years, with a mean age of 53.20 ± 15.78 years.

4.1.2.3 Ethnicity

The ethnicity ratio represented the nature of the study, with a much higher white (English, Welsh, Scottish, British, Northern Irish) population (see Table 17).

Table 17: Ethnicity of Respondents

Ethnicity	Total
Asian / Asian British (Indian, Pakistani, Bangladeshi, Chinese)	1
Black African	4
Black British	6
Black Caribbean	4
Mixed (White & Asian)	2
Mixed (White & Black African)	3
Mixed (White & Black Caribbean)	3
White (English, Welsh, Scottish, British, Northern Irish)	685
Other	6

4.1.3 Olympic Sport Participation

4.1.3.1 Winter Olympic Sports

The Winter Olympic Games was first run in 1924. Of the 714 replies, 69 GB Olympians competed in 11 sports in the Winter Olympic Games (Figure 13). One of the GB Olympians who competed at the Winter Olympic Games competed in two Olympic sports: alpine skiing and luge. One GB Olympian competed in athletics (sprinter) at the Summer Olympic Games and subsequently in bobsleigh at the Winter Olympic Games.

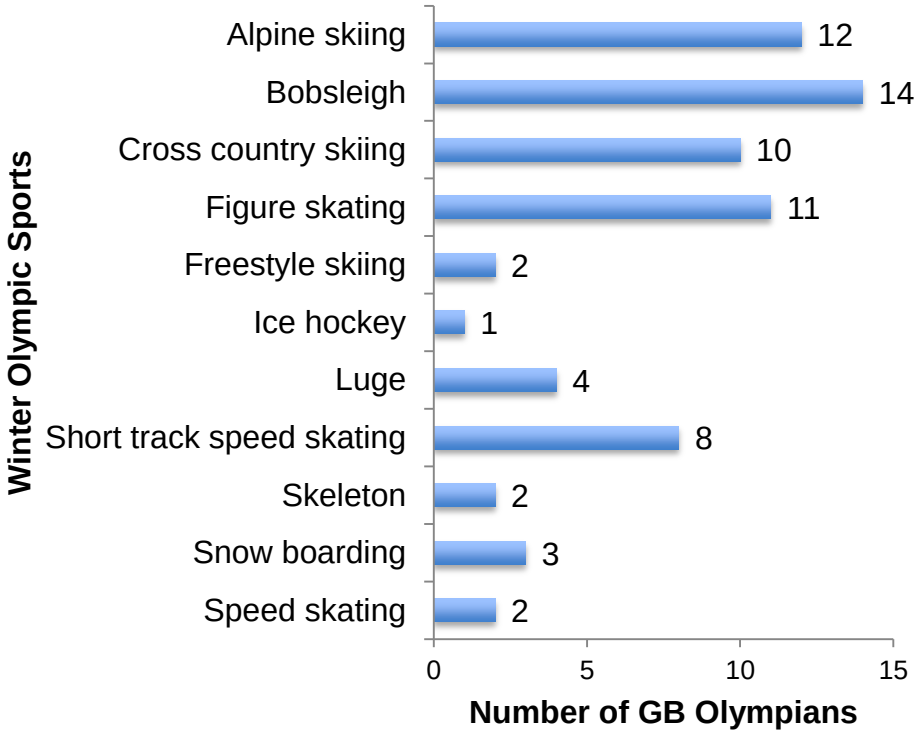


Figure 13: Response Rate by Winter Olympic Sports

4.1.3.2 Summer Olympic Sports

Of the 714 replies, 645 GB Olympians competed in 29 different sports at the Summer Olympic Games (Figure 14). Four of the GB Olympians who competed at the Summer Olympic Games competed in two Olympic sports: 1) athletics (sprint hurdles) and basketball, 2) judo and wrestling, 3) swimming and water polo, and 4) rowing and sailing. The percentage of returns per Athletics (track and field) is subdivided into: a) 70% running events, b) 10% jumping events, c) 10% throwing events, and d) 10% combined events (Figure 15). The running events comprise of sprints (100, 200 and 400 meters and the 100 meter relay), middle-distance running (800 and 1500 meters), long-distance running (steeplechase, 5000, and 10 000 meters), hurdling (110, 200, and 400 meter sprint hurdles), marathon, cross-country, and race walking. Jumping events include the long jump, triple jump, high jump, and pole vault. Throwing events include the shot put, javelin, and the hammer. Combined events included the heptathlon, modern pentathlon, and triathlon.

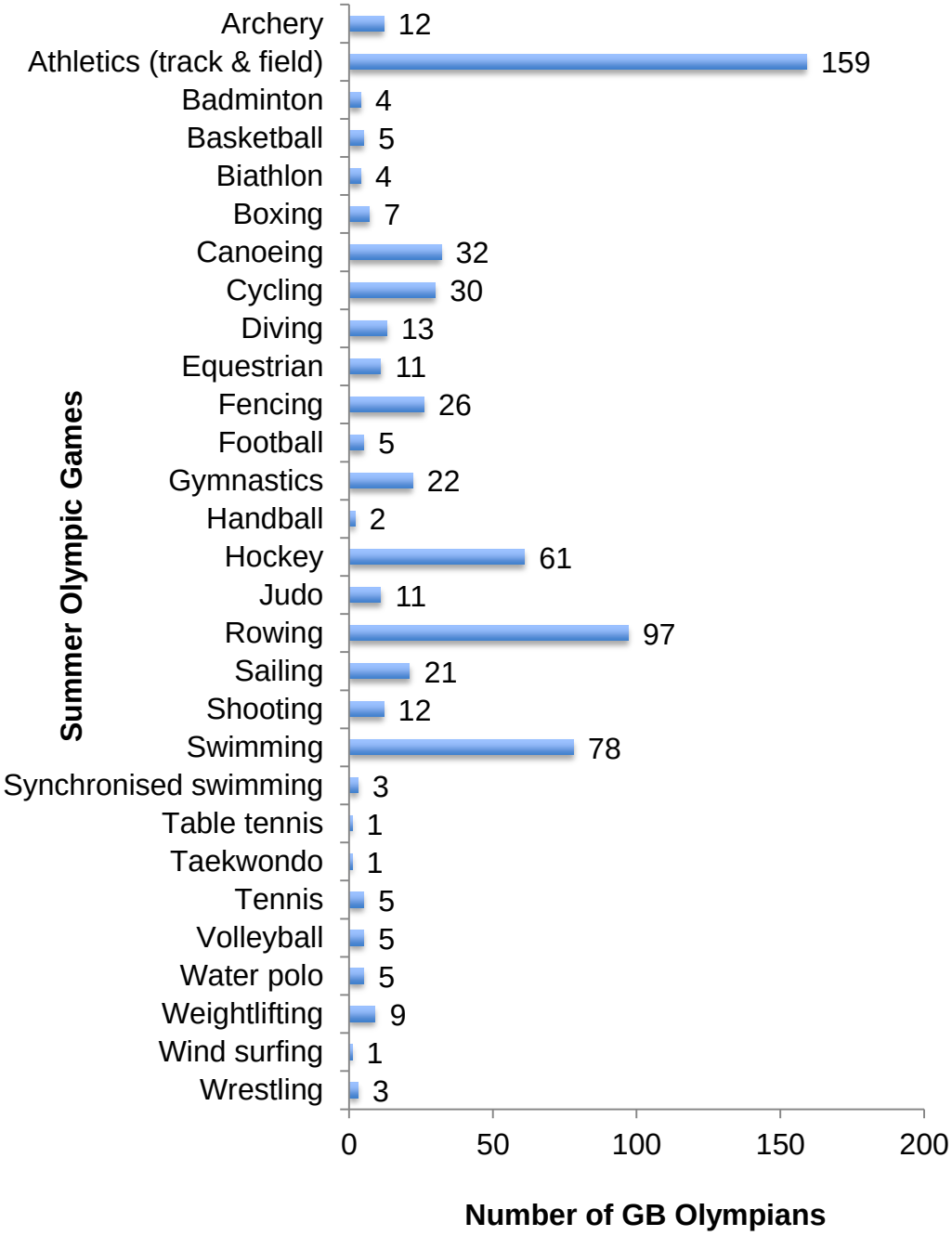


Figure 14: Response Rate by Summer Olympic Sports

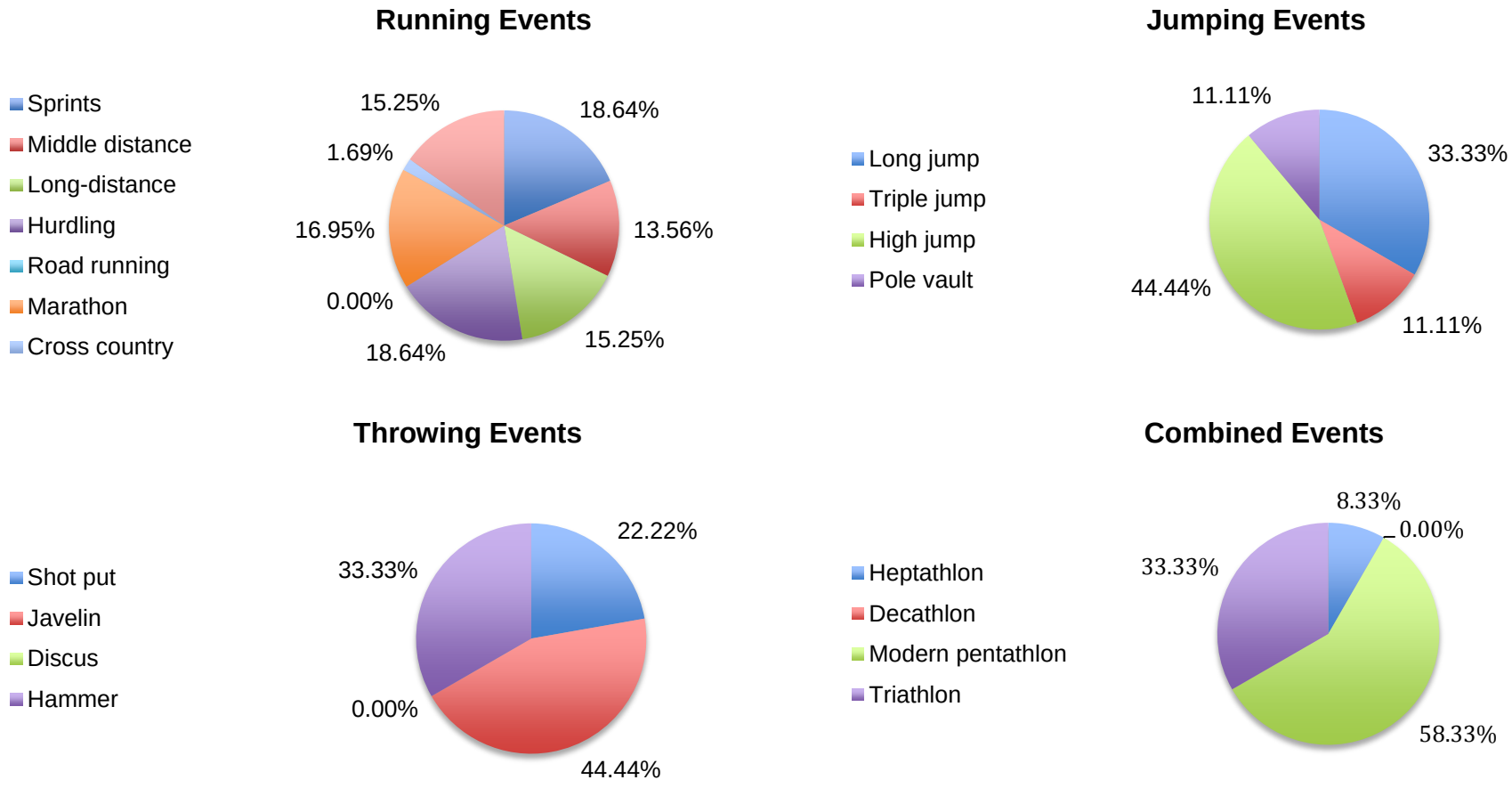


Figure 15: Breakdown of Response Rate by Athletics (Track and Field)

4.1.4 Summary of Recruitment

In summary, a total of 7230 invitations were distributed to 2742 GB Olympians residing in thirty different countries worldwide between the 22nd of May 2014 and the 31st of January 2015. Approximately, 4282 invitations to complete the Olympian questionnaire were sent by email and 2948 invitations were sent by post. There were 659 returns from GB Olympians living in the UK, and 55 returns from GB Olympians residing in 14 additional countries (see Figure 11). The return rate for GB Olympians residing in the UK was 26.3% compared to 23.1% for those living outside of the UK. Overall, there were 714 returns from the 2742 GB Olympians eligible for recruitment, which reflects a response rate of 26%. There was sufficient power for the primary research objectives (see section 2.2.11.1), with approximately 109 returns from GB Olympians aged less than 40 years of age, and 605 returns from those aged 40 years or older.

5.0 THE PREVALENCE OF INJURY, PAIN AND OSTEOARTHRITIS IN GREAT BRITAIN'S OLYMPIANS

5.1 Injury Patterns in Great Britain's Olympians

In this study, the prevalence of injury will be recorded according to: 1) the percentage of injured athletes, and 2) the mean number of injuries per athlete. The prevalence of injury was calculated among 689 of the 714 GB Olympians (19 to 97 years) who replied to the Olympian questionnaire. Injury data was missing for 25 GB Olympians (13 male; 12 female) who were excluded from the data analysis because they had not confirmed whether or not they had ever sustained a previous significant injury. A significant injury was defined as an injury that caused pain for most days during a one-month period and for which the individual consulted a medical professional or a health provider such as a general practitioner.

5.1.1 Prevalence of Injury in Great Britain's Olympians

Among the 689 GB Olympians that were included in the analysis, 66% sustained at least one significant injury (*n* = 455), and 34% (*n* = 234) reported no history of a previous significant injury. In total, 895 significant injuries were reported, and a mean of 2.0 injuries were sustained per athlete, during their athletic careers (see Table 18). Approximately 73% (*n* = 216/297) of female athletes sustained a significant injury compared to 61% (*n* = 239/392) of male athletes.

The percentage of injuries during sport participation (52.0%) was higher compared to non-sport related injuries (14.1%) ($P < 0.001$). The prevalence of non-sport related injuries was no different in females (14.8%) than in males (13.5%) ($P = 0.13$). The prevalence of sport injuries was also higher in females (57.9%) compared to males (47.4%) ($P < 0.001$). The injury rate in all GB Olympians was higher in training (30.5%) than in competition (21.2%) ($P = 0.004$). Interestingly the higher injury rate during sport participation among females was mostly borne out in training. The injury rate in training was significantly higher in females (37.4%) compared to males (25.3%) ($P < 0.001$). The injury rate in competition was no different between females (20.5%) compared to males (22.2%) ($P = 0.932$). There was no injury location recorded in 112 of the 895 reported significant injuries.

5.1.2 Prevalence of Injury by Sport

The number of significant sports injuries (injuries sustained in competition or training) in athletes who had competed in the Winter Olympic Games is recorded in Table 19 and Figure 16. The number of significant sports injuries in athletes who had competed in the Summer Olympic Games is recorded in Table 20 and Figure 17.

Table 18: Prevalence of Significant Injury among Great Britain's Olympians (*n* = 689)

Type of injury	Males	Females	Total
	% of injured athletes (Mean injuries per athlete)	% of injured athletes (Mean injuries per athlete)	% of injured athletes (Mean injuries per athlete)
Sports Injury:			
Competition	22.2 (2.0)	20.5 (2.2)	21.2 (2.1)
Training	25.3 (1.7)	37.4 (2.1)	30.5 (1.9)
Non-Sports Injury:			
Other	4.3 (2.2)	7.1 (1.8)	5.5 (2.0)
Unknown	9.2 (1.6)	7.7 (2.4)	8.6 (1.9)
All Injuries:			
Sports Injury	47.4 (1.8)	57.9 (2.2)	52.0 (2.0)
Non-Sports injury	13.5 (1.8)	14.8 (2.1)	14.1 (1.9)
Total injuries	61.0 (1.8)	72.7 (2.1)	66.0 (2.0)

Table 19: Injury Prevalence by Sport for Great Britain's Winter Olympians

Winter Olympic sport	Athletes per sport (m/f)*	Injuries (t/c/o/u)**	Injured athletes (sport)
Alpine skiing	12 (7/5)	16 (6/5/2/3)	8
Biathlon	2 (2/0)	4 (2/2/0/0)	2
Bobsleigh	13 (11/2)	11 (4/2/1/4)	5
Cross-country skiing	10 (7/3)	12 (3/9/0/0)	4
Figure skating	10 (2/8)	5 (5/0/0/0)	5
Ice hockey	1 (1/0)	1 (0/1/0/0)	1
Luge	3 (3/0)	3 (1/2/0/0)	2
Short tr. sp. skating	8 (4/4)	9 (8/1/0/0)	5
Skeleton	2 (0/2)	3 (2/1/0/0)	2
Skiing: freestyle	2 (1/1)	7 (4/3/0/0)	2
Snowboarding	3 (1/2)	24 (5/12/0/7)	3
Speed skating	2 (2/0)	0 (0/0/0/0)	-
Total	68 (41/27)	95 (40/38/3/14)	39

*m, males; f, females; **occurred in: t, training; c, competition; o, other (non-sport); u, unknown.

Table 20: Injury Prevalence by Sport for Great Britain's Summer Olympians

Summer Olympic sport	Athletes per sport (m/f)*	Injuries (t/c/o/u)**	Injured athletes (sport)
Archery	11 (3/8)	6 (2/2/1/1)	3
Athletics	153 (83/70)	235 (122/73/14/26)	99
Badminton	4 (2/2)	4 (3/0/0/1)	1
Basketball	5 (4/1)	8 (2/4/0/2)	3
Boxing	6 (6/0)	1 (0/0/0/1)	-
Canoeing	30 (18/12)	27 (11/4/10/2)	9
Cycling	27 (19/8)	33 (8/20/2/3)	16
Diving	13 (4/9)	23 (10/4/5/4)	7
Equestrian	10 (3/7)	15 (4/9/0/2)	5
Fencing	26 (14/12)	28 (10/12/4/2)	14
Football	5 (5/0)	5 (0/4/0/1)	3
Gymnastics	21 (9/12)	34 (21/10/1/2)	17
Handball	2 (1/1)	2 (0/1/0/1)	1
Hockey	58 (46/12)	74 (16/38/10/10)	30
Judo	11 (6/5)	28 (13/13/0/2)	8
Rowing	95 (54/41)	111 (67/21/12/11)	49
Sailing	21 (17/4)	24 (9/7/2/6)	9
Shooting	12 (7/5)	13 (3/7/0/3)	7
Swimming	75 (26/49)	67 (30/15/8/14)	30
Syn. swimming	3 (0/3)	5 (5/0/0/0)	2
Table tennis	1 (1/0)	2 (0/2/0/0)	1
Taekwondo	1 (0/1)	-	-
Tennis	5 (4/1)	8 (1/6/1/0)	2
Volleyball	5 (3/2)	11 (9/2/0/0)	3
Water polo	5 (3/2)	6 (6/0/0/0)	2
Weightlifting	9 (7/2)	23 (10/10/1/2)	9
Wind surfing	1 (1/0)	3 (0/0/2/1)	-
Wrestling	3 (3/0)	4 (1/2/0/1)	2
Total	622 (353/269)	800 (363/266/73/98)	332

*m, males; f, females; **occurred in: t, training; c, competition; o, other (non-sport); u, unknown.

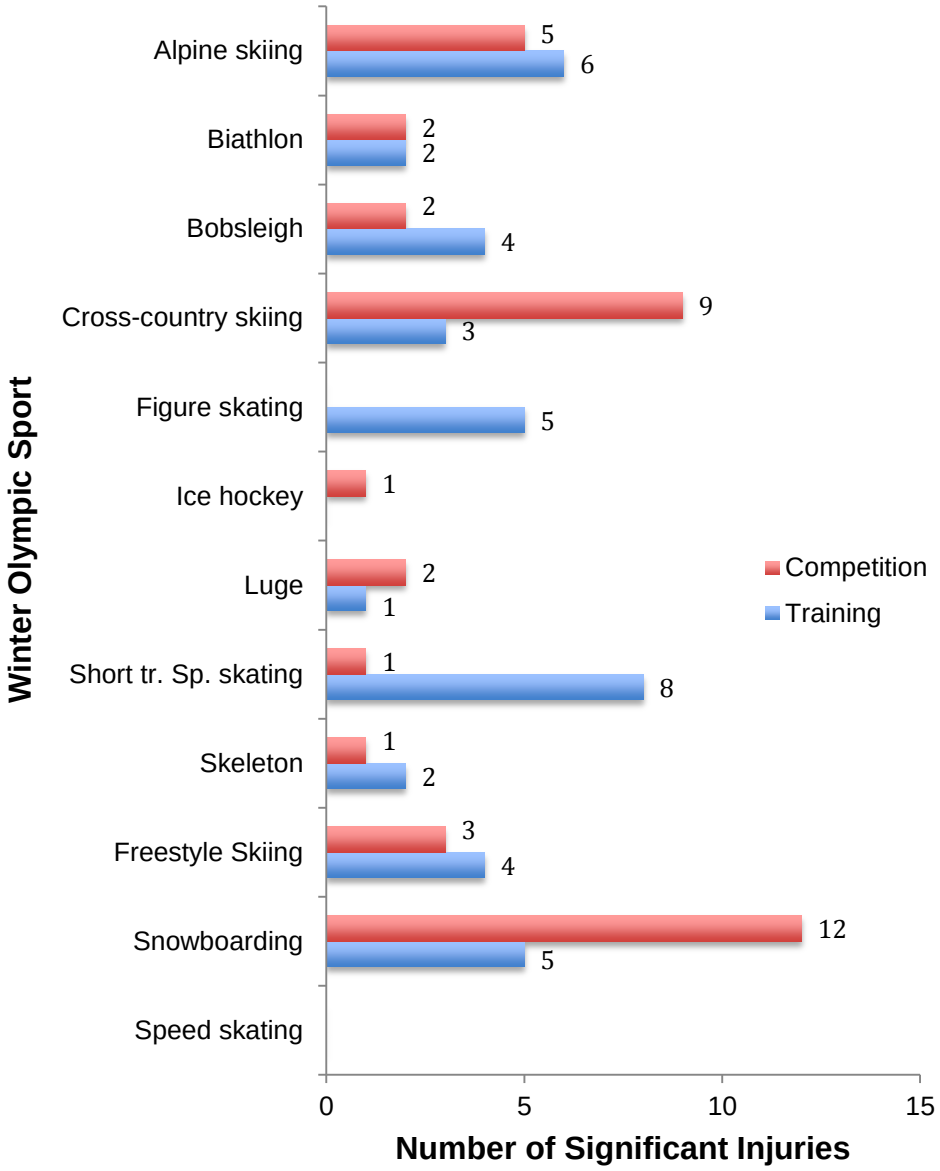


Figure 16: Number of Significant Injuries by Sport among Great Britain's Winter Olympians

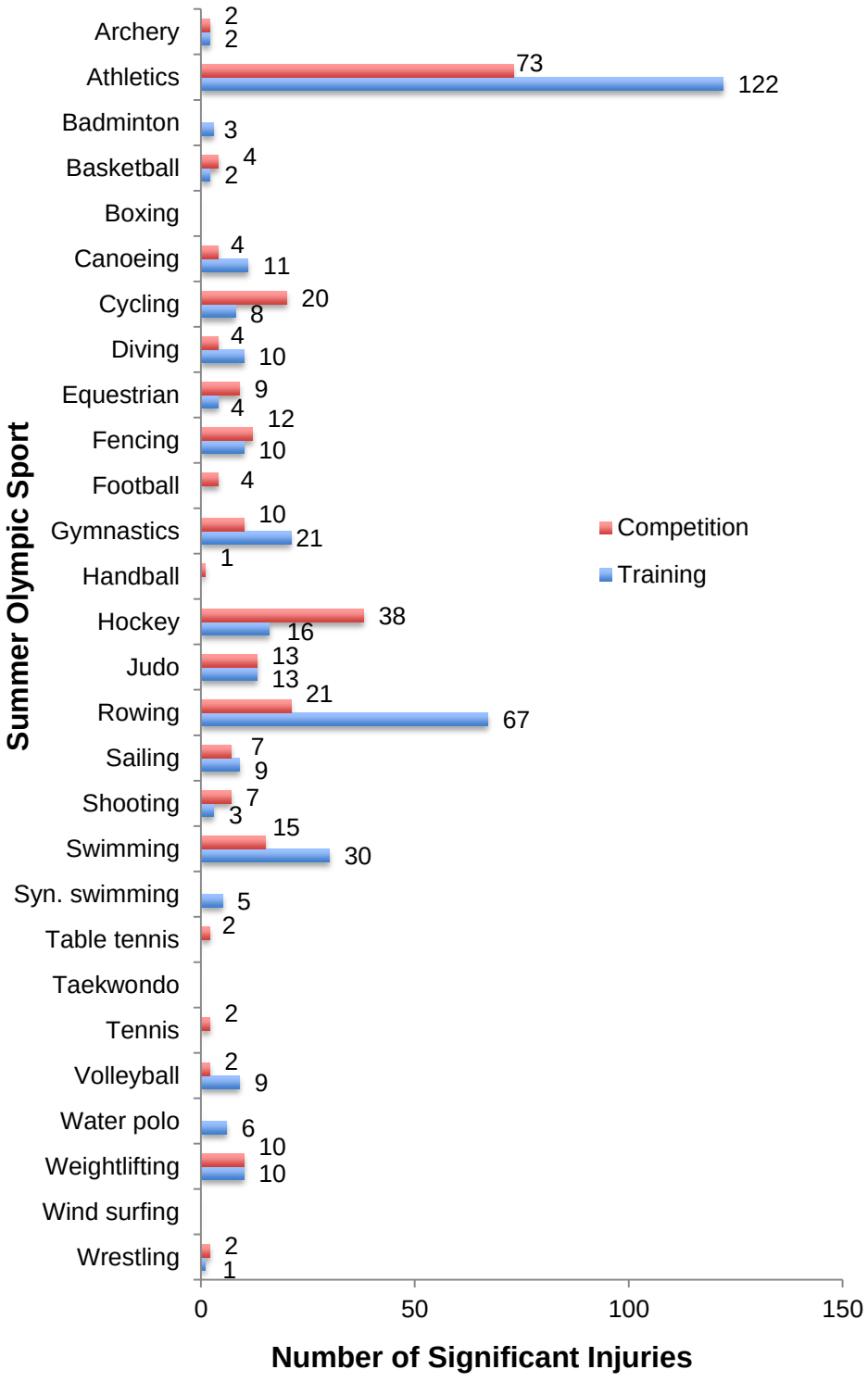


Figure 17: Number of Significant Injuries by Sport among Great Britain's Summer Olympians

5.1.3 Injury location in Great Britain's Olympians

There were a total of 895 significant injuries recorded in 25 different body locations (see Table 21). The greatest number of recorded injuries occurred at the knee (18.7%), lower back (16.8%), shoulder (11.7%), ankle (9.5%), lower leg (6.2%), foot (5.5%), wrist (3.5%), thigh (3.4%), and the Achilles tendon (3.4%). The most prominent injury location for male athletes (see Figure 18) was the knee (19.9%), shoulder (13.9%), lower back (13.7%), and ankle (7.9%), followed by the lower leg (7.6%), foot (4.4%), thigh (4.4%) and the Achilles tendon (3.7%). The most prominent injury location for female athletes was the lower back (19.7%), knee (17.5%), ankle (11.0%), and shoulder (9.7%), followed by the foot (6.5%), lower leg (4.8%), the Achilles tendon (3.0%) and the thigh (2.4%).

The most prominent injury locations in GB Olympians who had participated in the Winter Olympic Games were the knee (22.0%), shoulder (20.9%), lower back (13.2%), ankle (12.1%), head (5.5%), foot (5.5%), wrist (4.4%), and lower leg (3.3%). The most prominent injury locations in GB Olympians who had participated in the Summer Olympic Games were the knee (18.3%), lower back (6.5%), shoulder (10.7%), ankle (9.2%), lower leg (6.4%), foot (5.5%), thigh (3.7%), Achilles tendon (3.6%), wrist (3.4%), elbow (2.7%) and hip (2.7%) (see Table 22).

Table 21: Location of Injuries (%) within Great Britain's Olympians (*n* = 689)

Body part	Number of female injuries (%)	Number of male injuries (%)	Total number of injuries (%)
Knee	81 (17.5)	86 (19.9)	167 (18.7)
Lower back	91 (19.7)	59 (13.7)	150 (16.8)
Shoulder	45 (9.7)	60 (13.9)	105 (11.7)
Ankle	51 (11.0)	34 (7.9)	85 (9.5)
Lower leg	22 (4.8)	33 (7.6)	55 (6.2)
Foot / toe	30 (6.5)	19 (4.4)	49 (5.5)
Wrist	18 (3.9)	13 (3.0)	31 (3.5)
Thigh	11 (2.4)	19 (4.4)	30 (3.4)
Achilles ten.	14 (3.0)	16 (3.7)	30 (3.4)
Hip	11 (2.4)	13 (3.0)	24 (2.7)
Elbow	16 (3.5)	7 (1.6)	23 (2.6)
Other / Unknown	12 (2.6)	11 (2.6)	23 (2.6)
Finger	9 (1.9)	13 (3.0)	22 (2.5)
Sternum / rib	9 (1.9)	7 (1.6)	16 (1.8)
Neck	9 (1.9)	6 (1.4)	15 (1.7)
Upper back	8 (1.7)	6 (1.4)	14 (1.6)
Head	9 (1.9)	3 (0.7)	12 (1.3)
Face	2 (0.4)	7 (1.6)	9 (1.0)
Forearm	6 (1.3)	3 (0.7)	9 (1.0)
Groin	2 (0.4)	5 (1.2)	7 (0.8)
Hand	2 (0.4)	4 (0.9)	6 (0.7)
Pelvis / SIJ	3 (0.7)	1 (0.2)	4 (0.5)
Upper arm	1 (0.2)	3 (0.7)	4 (0.5)
Abdomen	-	3 (0.7)	3 (0.3)
Thumb	1 (0.2)	1 (0.2)	2 (0.2)
Total	463	432	895

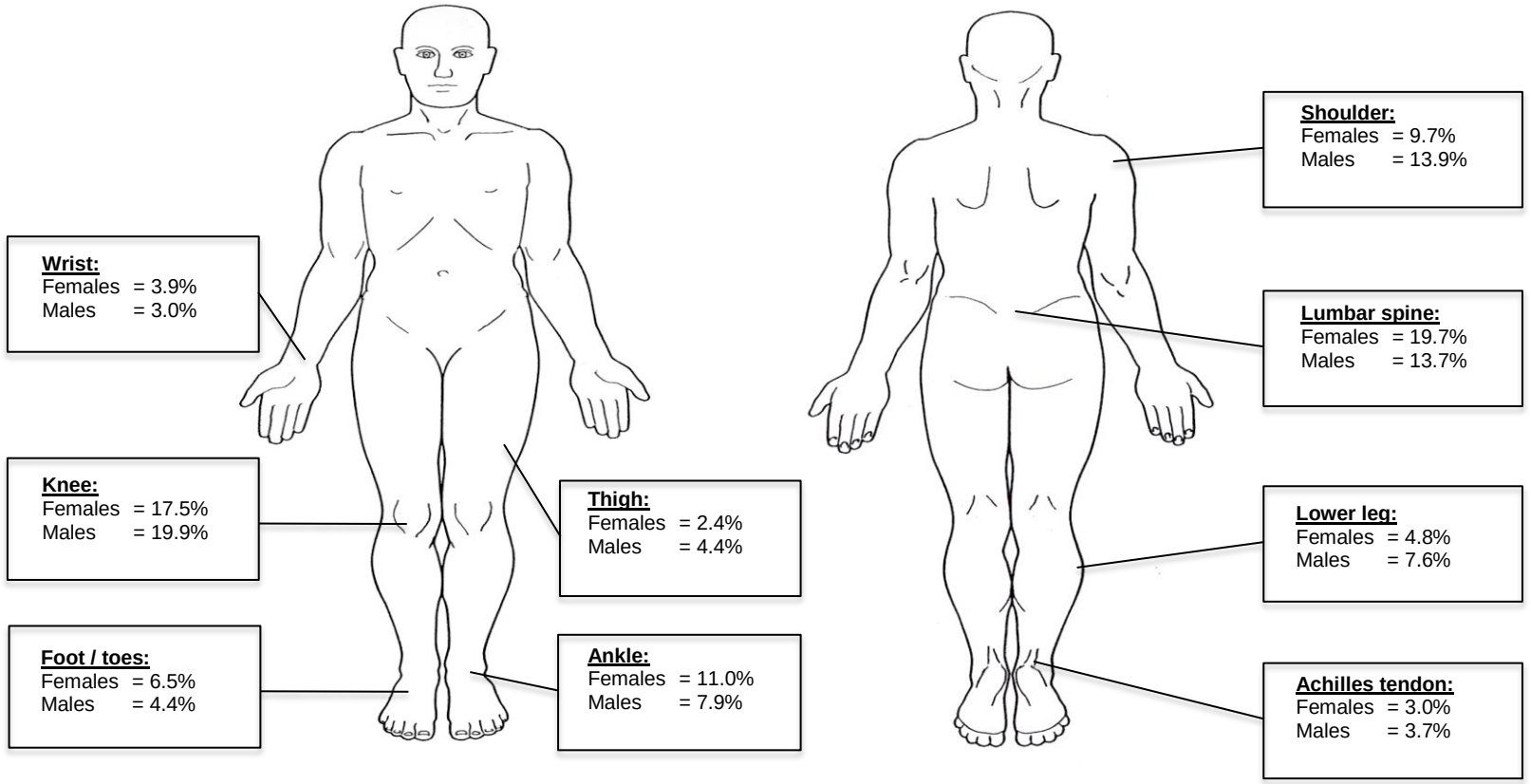


Figure 18: The Most Prevalent Locations of Injury in Male and Female GB Olympians

Table 22: Location of Injuries (%) within Great Britain's Winter and Summer Olympians (*n* = 689)

Location	Injuries in Winter Olympic athletes (%)	Injuries in Summer Olympic athletes (%)	Total injuries (%)
Face	1 (1.1)	8 (1.0)	9 (1.0)
Head	5 (5.5)	7 (0.9)	12 (1.3)
Neck	-	15 (1.9)	15 (1.7)
Upper back	2 (2.2)	12 (1.5)	14 (1.6)
Sternum	-	16 (2.0)	16 (1.8)
Lower back	12 (13.2)	138 (17.2)	150 (16.8)
Abdomen	-	3 (0.4)	3 (0.3)
Pelvis / sacrum	1 (1.1)	3 (0.4)	4 (0.5)
Shoulder	19 (20.9)	86 (10.7)	105 (11.7)
Upper arm	-	4 (0.5)	4 (0.5)
Elbow	1 (1.1)	22 (2.7)	23 (2.6)
Forearm	1 (1.1)	8 (1.0)	9 (1.0)
Wrist	4 (4.4)	27 (3.4)	31 (3.5)
Hand	-	6 (0.8)	6 (0.7)
Finger	1 (1.1)	21 (2.6)	22 (2.5)
Thumb	-	2 (0.3)	2 (0.2)
Hip	2 (2.2)	22 (2.7)	24 (2.7)
Groin	-	7 (0.9)	7 (0.8)
Thigh	-	30 (3.7)	30 (3.4)
Knee	20 (22.0)	147 (18.3)	167 (18.7)
Lower leg	3 (3.3)	52 (6.5)	55 (6.2)
Achilles tendon	1 (1.1)	29 (3.6)	30 (3.4)
Ankle	11 (12.1)	74 (9.2)	85 (9.5)
Foot / toe	5 (5.5)	44 (5.5)	49 (5.5)
Other / unknown	2 (2.2)	21 (2.6)	23 (2.6)
Total	91	804	895

5.1.4 Injury Type in Great Britain's Olympians

The most common injury type among GB Olympians (*n* = 689) were traumatic fractures (18.1%: 162/895), sprain (injury of joint and / or ligaments) (16.9%; 151/895) and tendinosis / tendinopathy (10.1%; 90/895) (see Table 23). Approximately 9.5% (85/895) of injuries were significant muscle injuries, 6.7% (60/895) were cartilage injuries, 6.0%

(54/895) were dislocations / subluxations, 5.0% (45/895) were stress fractures and 4.8% (43/895) were intervertebral disc injuries. Twenty-six cases (2.9%; 26/895) were categorised as unknown because there was no injury type recorded. The most common injury type in female athletes was sprain (20.3%; 94/895), fracture (16.0%; 74/895), and muscle injury (9.3%; 43/895). The most common injury type in male athletes was fracture (20.4%; 88/895), sprain (13.2%; 57/895), and tendinosis / tendinopathy (11.1%; 48/895).

There were approximately twice as many stress fractures and dislocations / subluxations reported in male athletes. A single catastrophic injury, with spinal cord injury and paraplegia as the outcome, occurred in horse riding. Approximately 28.1% (47/167) of all significant knee injuries were reported to be a cartilage injury, 25.1% were joint injuries (injury of joint and / or ligaments), 10.2% (17/167) were ligamentous rupture and 10.2% (17/167) were tendinosis / tendinopathy. Injuries to the intervertebral disc accounted for 28.0% (42/150) of lower back injuries, and approximately 29.5% (31/105) of all significant shoulder injuries were dislocations and 21.9% (23/105) were reported to be fractures. Sprain (injury of joint and / or ligament) (44.7%; 38/85) was the most common injury type at the ankle, followed by fracture (23.5%; 20/85) and tendinosis / tendinopathy (18.8%; 16/85). The most common injury type at the hip was sprain (injury of joint and / or ligaments) (29.2%; 7/24), cartilage injury (8.3%; 2/24), muscle injury (8.3%; 2/24) and fracture (4.2%; 1/24).

Table 23: Injury Type (%) in Great Britain's Olympians (*n* = 689)

Type of injury	Injuries in male (%)	Injuries in female (%)	Total number of injuries (%)
Fracture	88 (20.4)	74 (16.0)	162 (18.1)
Sprain (joint +/- ligaments)	57 (13.2)	94 (20.3)	151 (16.9)
Tendinosis / tendinopathy	48 (11.1)	42 (9.1)	90 (10.1)
Muscle injury (strain)	42 (9.7)	43 (9.3)	85 (9.5)
Other	28 (6.5)	34 (7.3)	62 (6.9)
Cartilage injury	30 (6.9)	30 (6.5)	60 (6.7)
Dislocation / subluxation	36 (8.3)	18 (3.9)	54 (6.0)
Stress fracture	15 (3.5)	30 (6.5)	45 (5.0)
Disc	16 (3.7)	27 (5.8)	43 (4.8)
Unknown	14 (3.2)	12 (2.6)	26 (2.9)
Ligamentous rupture	10 (2.3)	12 (2.6)	22 (2.5)
Arthritis / synovitis / bursitis	17 (3.9)	4 (0.7)	21 (2.4)
Tendon rupture	9 (2.1)	6 (1.3)	15 (1.7)
Nerve injury	6 (1.4)	8 (1.7)	14 (1.6)
Contusion / haematoma	2 (0.5)	9 (1.9)	11 (1.2)
No location codes	4 (0.9)	5 (1.1)	9 (1.0)
Concussion	0 (0.0)	6 (1.3)	6 (0.7)
Compartment syndrome	4 (0.9)	-	4 (0.5)
Fasciitis	-	3 (0.7)	3 (0.3)
Impingement	2 (0.5)	1 (0.2)	3 (0.3)
Laceration	1 (0.2)	2 (0.4)	3 (0.3)
Muscle cramps	1 (0.2)	2 (0.4)	3 (0.3)
Dental injury	1 (0.2)	-	1 (0.1)
Amputation	1 (0.2)	-	1 (0.1)
Shin splints	-	1 (0.2)	1 (0.1)
Total	432	463	895

5.1.5 Injury Mechanism in Great Britain's Olympians

The number of sport related injuries in competition (*n* = 216, 50.5%), were comparable to the number of sport related injuries that occurred in training (*n* = 212, 49.5%). The most common reported injury mechanism in training (see Table 24) was non-contact trauma (*n* = 155, 73.1%). The most common reported injury mechanism in competition

(see Table 25) was also non-contact trauma (*n* = 153, 70.8%). The percentage of injuries sustained through contact with another athlete was higher in males compared to females in training (*P* = 0.02) and competition (*P* = 0.029).

Table 24: Injury Mechanism (%) in Training among Great Britain's Olympians

Injury Mechanism – Training	Injuries in males (%)	Injuries in females (%)	Total
Non-contact trauma	58 (64.4)	97 (79.5)	155 (73.1)
Recurrence of previous injury	-	-	-
Contact with another athlete	11 (12.2)	4 (3.3)	15 (7.1)
Contact with moving object	-	3 (2.5)	3 (1.4)
Contact with stagnant object	3 (3.3)	2 (1.6)	5 (2.4)
Field or play conditions	2 (2.2)	-	2 (0.9)
Other	16 (17.8)	16 (13.1)	32 (15.1)
Total	90	122	212

Table 25: Injury Mechanism (%) in Competition among Great Britain's Olympians

Injury Mechanism - Competition	Injuries in males (%)	Injuries in females (%)	Total
Non-contact trauma	83 (68.0)	70 (74.5)	153 (70.8)
Contact with another athlete	23 (18.9)	8 (8.5)	31 (14.4)
Contact with moving object	2 (1.6)	3 (3.2)	5 (2.3)
Contact with stagnant object	2 (1.6)	1 (1.1)	3 (3.2)
Other	6 (4.9)	7 (7.4)	13 (13.8)
Missing	6 (4.9)	5 (5.3)	11 (11.7)
Total	122	94	216

5.1.6 Injury and Hypermobility in Great Britain's Olympians

Injury is not associated with generalised joint hypermobility (Beighton ≥ 4/9). Those with generalised joint hypermobility (GJH) (Beighton ≥ 4/9) in their twenties were no more likely to report a significant injury in the lower back [OR 0.99; 95% CI, 0.55-1.82), hip [OR 0.60; 95% CI, 0.14-2.59], knee [OR 1.21; 95% CI, 0.69-2.14], or ankle [OR 1.28; 95% CI, 0.64-2.57]. Overall, there was no significant risk of injury in those with GJH in their twenties [OR 1.11; 95% CI, 0.67-1.83], and there was no significant difference in female [OR 1.25; 95% CI, 0.62-2.50] or male GB Olympians [OR 0.76; 95% CI, 0.35-1.65]. There was no significant risk of injury in GB Olympians with GJH based on a current Beighton score (≥ 4/9) [OR 0.66; 95% CI, 0.35-1.23], and there was no significant risk of injury in either female [OR 0.70; 95% CI, 0.32-1.53] or male GB Olympians [OR 0.26; 95% CI, 0.07-0.98].

5.2 The Prevalence of Musculoskeletal Pain in Great Britain's Olympians

The sample consisted of 714 GB Olympians, ranging in age from 19 to 97 years of age (*M* = 59.05, *SD* = 16.87). Pain data was missing for 55 GB Olympians who were excluded from the data analysis; hence the following results are reported on 659 GB Olympians. Data was collected using the pain manikin and the most severe joint was selected, if bilateral. The prevalence of any recent pain experienced anywhere in the body for most days for at least one month was 66.2% (436/659). Approximately 32.7% (216/659) of the sample complained of lumbar

spine pain, 25.6% (169/659) reported pain at the knee, 23.0% (151/659) at the hip, 14.1% (93/659) at the ankle joint / foot, 9.3% (61/659) at the cervical spine, and 2.0% (13/659) at the 1st metatarsophalangeal joint and 1.8% (12/659) at the 1st carpometacarpal joint.

5.2.1 The Prevalence of Musculoskeletal Pain according to Age

The prevalence of recent pain experienced anywhere in the body for most days for at least one month was no different in those aged 60 years and older (67.9%; 222/327), compared to those aged between 40-59 years (65.4%; 155/237), and less than 40 years of age (58.9%; 56/95) (*P* = 0.269). Knee pain was more prevalent in GB Olympians aged 60 years and older (29.1%; 95/327), compared to those aged between 40-59 years (21.9%; 52/237), and less than 40 years of age (23.2%; 22/95) (see Table 26) (*P* = 0.135). A higher prevalence of pain was detected among the younger GB Olympians (less than 40 years) at the lumbar spine (38.9%; 37/95), hip (26.3%; 25/95), ankle joint / foot (16.8%; 16/95), and the cervical spine (12.6%; 12/95). The prevalence of pain was marginally lower in younger GB Olympians at the 1st metatarsophalangeal joint (1.1%; 1/95), and the 1st carpometacarpal joint (1.1%; 1/95).

Table 26: The Prevalence of Pain in Great Britain's Olympians according to Age

	Less than 40 years	40 to 59 years	60 years and older
Cervical Spine	12.6%	8.9%	8.6%
Lumbar Spine	38.9%	34.6%	29.7%
Hip joint	26.3%	19.0%	24.8%
Knee joint	23.2%	21.9%	29.1%
Ankle joint / foot	16.8%	14.8%	12.8%
1st metatarsophalangeal joint	1.1%	1.7%	2.4%
1st carpometacarpal joint	1.1%	1.7%	2.1%

5.2.2 The Prevalence of Musculoskeletal Pain according to Gender

The prevalence of musculoskeletal pain among GB Olympians was reported to be similar between genders (see Figure 19). Musculoskeletal pain was most prevalent among the male GB Olympians at the lumbar spine (31.7%; 120/379), the knee joint (25.6%; 97/379), hip joint (23.2%; 88/379), ankle joint / foot (13.2%; 50/379), cervical spine (9.0%; 34/379), 1st metatarsophalangeal joint (1.6%; 6/379), and the 1st carpometacarpal joint (1.3%; 5/379). The prevalence of musculoskeletal pain among female GB Olympians was also greatest at the lumbar spine (34.3%; 96/280), the knee joint (25.7%; 72/280), hip (22.5%; 63/280), the ankle joint / foot (15.4%; 43/280), the 1st metatarsophalangeal joint (2.5%; 7/280), and the 1st carpometacarpal joint (2.5%; 7/280).

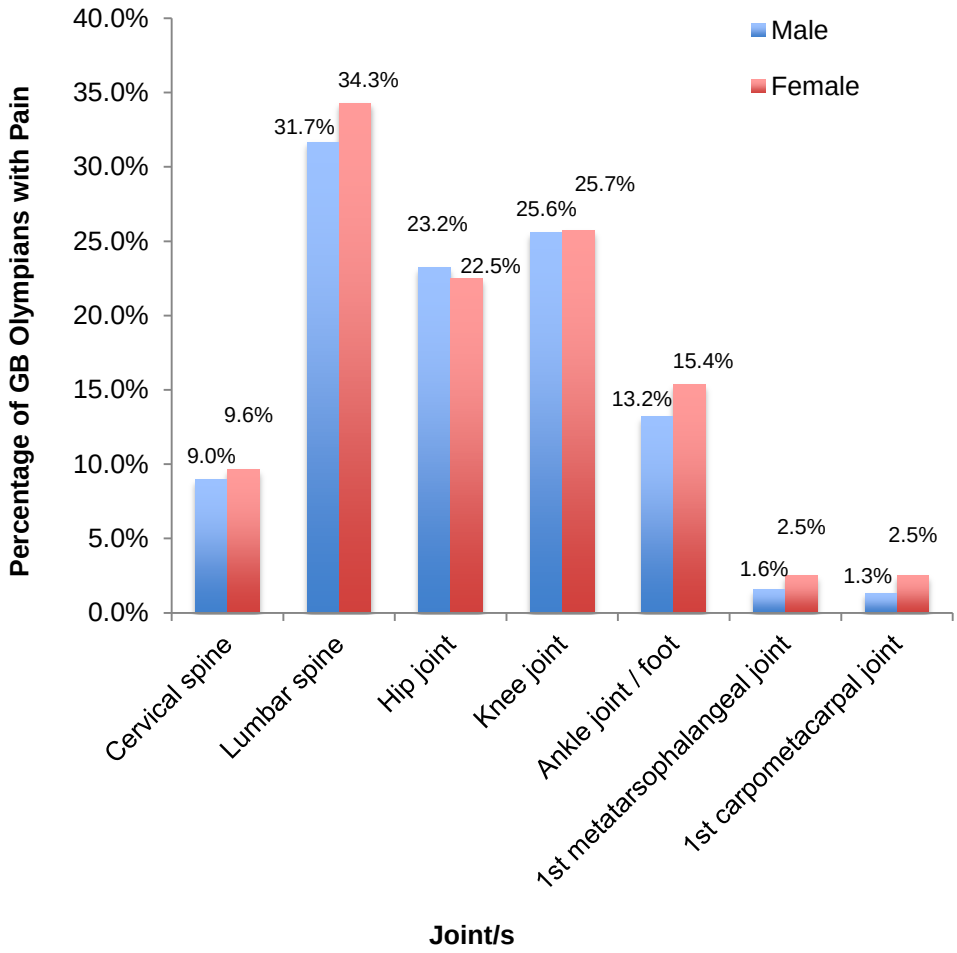


Figure 19: The Prevalence of Pain in Great Britain's Olympians according to Gender

5.2.3 The Prevalence of Pain according to Body Mass Index

Pain and body mass index (BMI) data was missing for 62 GB Olympians who were excluded from the data analysis; hence the following results are reported on 652 GB Olympians. The prevalence of recent pain experienced anywhere in the body for most days for at least one month was not statistically different in GB Olympians with an obese BMI classification ($\geq$ 30 kg/m^2) (37.9%; 22/58), compared to those in the

overweight BMI category (32.4%; 62/191), and those with a normal BMI category (31.5%; 127/403) (*P* = 0.111).

Pain was most prevalent among GB Olympians at the lumbar spine (34.5%; 20/58), hip (29.3%; 17/58), knee (53.4%; 31/58), ankle (15.5%; 9/58), and 1st carpometacarpal joint (6.9%; 4/58) in GB Olympians with an obese BMI classification ($\geq$ 30 kg/m^2) (see Table 27). The prevalence of pain was higher at the lumbar spine (30.3%; 122/403) in those classified with a normal BMI (18.50-24.99 kg/m^2). Pain was also higher at the lumbar spine (38.2%; 73/191) in those in the overweight BMI category (25.00-29.00 kg/m^2).

Table 27: The Prevalence of Pain in Great Britain's Olympians according to Body Mass Index

Joint	Normal (< 25.00 kg/m^2)	Overweight (25.00-29.99 kg/m^2)	Obese ($\geq$ 30.00 kg/m^2)
Cervical Spine	9.4%	9.9%	6.9%
Lumbar Spine	30.3%	38.2%	34.5%
Hip joint	22.6%	22.5%	29.3%
Knee joint	22.1%	24.1%	53.4%
Ankle joint / foot	14.4%	12.6%	15.5%
1st MTP joint*	1.7%	3.1%	0%
1st CMC joint**	1.5%	1.0%	6.9%

*1st metatarsophalangeal joint; **1st carpometacarpal joint

5.2.4 The Prevalence of Musculoskeletal Pain in Relation to Sport

The largest proportion of GB Olympians who replied to the Olympian questionnaire and were included in this analysis competed in the following Olympic sports: athletics (20.9%; 149/714), rowing (12.3%;

88/714), swimming (10.4%; 74/714), hockey (7.6%; 54/714), canoeing (3.9%; 28/714) and cycling (3.9%; 28/714). Of these sports, the prevalence of recent pain experienced anywhere in the body for most days for at least one month was higher in athletics (72.5%; 108/149), hockey (70.4%; 38/54), canoeing (60.7%; 17/28), cycling (57.1%; 16/28), and rowing (56.8%; 50/88). The prevalence of pain at the hip, knee, and the lumbar spine was higher in athletics. The prevalence of pain at the hip and knee was lowest in non-weight bearing loading sports (see Table 28).

Table 28: Prevalence of Pain according to Sport

Sport	Hip Pain (%)	Knee Pain (%)	Lumbar Spine Pain (%)
Athletics (*n* = 149)	45 (30.2)	52 (34.9)	50 (33.6)
Hockey (*n* = 54)	14 (25.9)	18 (33.3)	14 (25.9)
Canoeing (*n* = 28)	6 (21.4)	4 (14.3)	6 (21.4)
Cycling (*n* = 28)	4 (14.3)	7 (25.0)	9 (32.1)
Swimming (*n* = 74)	12 (16.2)	17 (23.0)	25 (33.8)
Rowing (*n* = 88)	18 (20.5)	11 (12.5)	24 (27.3)

The prevalence of pain was higher among GB Olympians who had competed in weight-bearing loading-sports (70.4%; 285/405), compared to those in non-weight-bearing loading-sports (59.4%; 151/254) (*P* = 0.005). However, the prevalence of pain at the cervical and lumbar spine, and the 1st carpometacarpal joint (see Figure 20) was similar in GB Olympians who had competed in non-weight-bearing loading-sports and those who had taken part in weight-bearing loading-sports. Of the GB Olympians recorded as competing in weight-bearing loading-sports,

26.7% (108/405) complained of hip pain, 30.4% (123/405) reported knee pain, and 16.3% (66/405) reported pain in the ankle joint / foot respectively. Of the GB Olympians listed as competing in non-weight-bearing loading-sports, 16.9% (43/254) complained of hip pain (*P* = 0.015), 18.1% (46/254) reported knee pain (*P* = 0.001), and 10.6% (27/254) reported pain in the ankle joint / foot (*P* = 0.055).

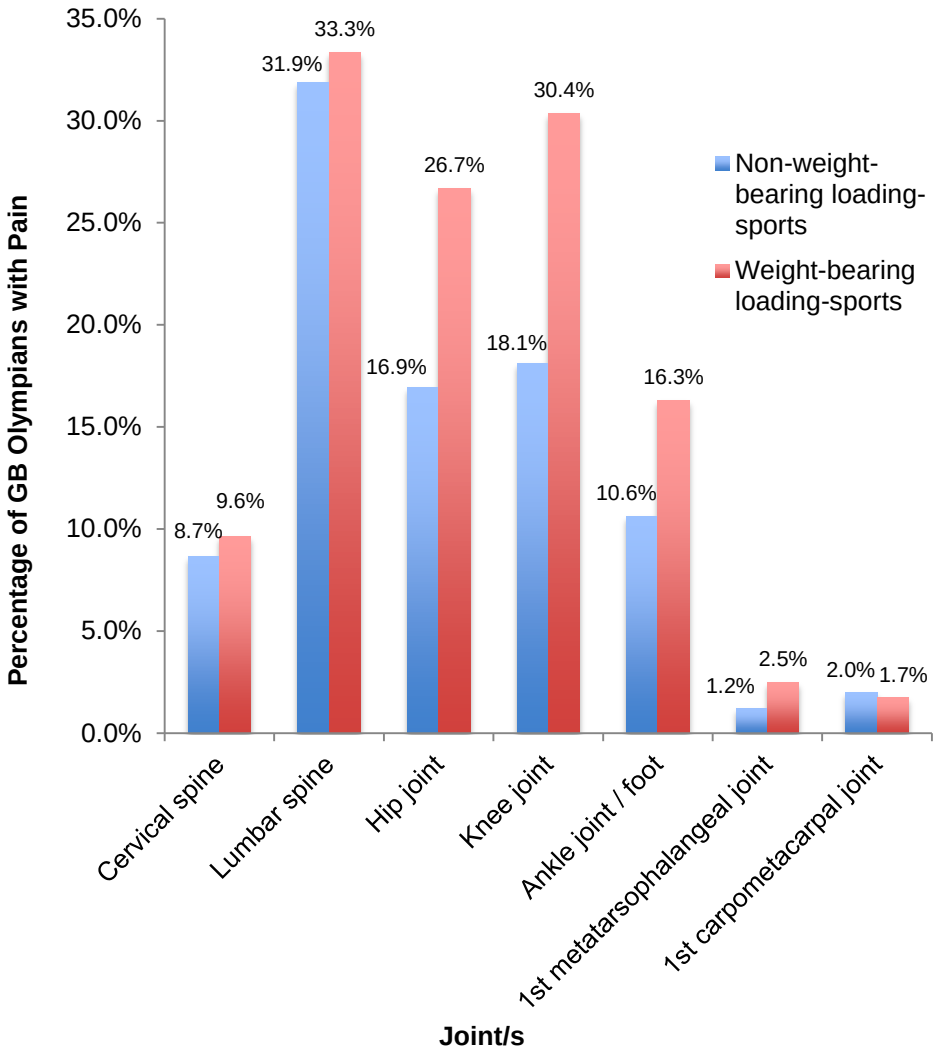


Figure 20: The Prevalence of Pain in Great Britain's Olympians according to Weight-Bearing Loading-Sports

5.2.5 Musculoskeletal Pain and Injury in Great Britain's Olympians

Injury was the strongest risk factor associated with pain at all joint sites examined. Intra-articular joint injuries were the most common types of injury associated with pain. In total, there were 169 GB Olympians (aged 19 to 97 years) with knee pain, 151 with hip pain, and 216 with lumbar spine pain. Of the 169 GB Olympians with knee pain, 43 had sustained at least one previous significant knee injury (*n* = 58 total knee injuries). These injuries consisted of 17 cartilage injuries, 14 joint sprains (injury of joint and / or ligaments), 4 ligamentous ruptures, 2 contusions, 3 dislocations, 6 tendinosis / tendinopathy, and 12 other types of injury. Of the 151 GB Olympians with hip pain, 11 had sustained a previous significant hip injury (*n* = 24 total injuries). These injuries consisted of 2 cartilage injuries, 1 fracture, 1 stress fracture, 2 muscle injuries, 7 joint sprains (injury to joint and / or ligaments), and 11 other types of injury. Of the 216 GB Olympians with lumbar spine pain, 51 (*n* = 52 total injuries) had sustained a previous significant injury to the lumbar spine. These consisted of 13 injuries to the intervertebral disc, 10 muscle injuries, 10 joint sprains (joint injury and / or ligaments), 6 fractures, 3 stress fractures, 2 nerve injuries, 1 contusion, and 7 other types of injury.

5.3 The Prevalence of Osteoarthritis in Great Britain's Olympians

Osteoarthritis data was missing for eight GB Olympians aged 40 years and older who replied to the Olympian questionnaire; hence the results are reported on 597 GB Olympians. The prevalence of OA was

recorded at the most severe joint, if bilateral. There were 190 GB Olympians aged 40 years and older (31.8%; 190/597) who self-reported that they had previously been diagnosed with OA by a physician. The knee joint was most commonly affected by OA in GB Olympians (14.2% 85/597), followed by the hip (11.1%; 66/597), lumbar spine (5.0%; 30/597), the interphalangeal joints (2.3%; 14/597), cervical spine (2.2%; 13/597), 1st metatarsophalangeal joint (1.5%; 9/597), ankle joint (1.3%; 8/597), midtarsal joints (1.3%; 8/597), shoulder (1.3%; 8/597), the 1st carpometacarpal joint (1.2%; 7/597), and wrist (1.2%; 7/597). Less than one per cent reported OA at the sacroiliac joint (0.2%; 1/597), acromioclavicular joint (0.2%; 1/597), and elbow (0.2%; 1/597) (see Table 29).

Table 29: Prevalence of Osteoarthritis in Great Britain's Olympians Aged 40 Years and Older

Joint	Male (*n* = 356) (%)	Female (*n* = 241) (%)	Total Prevalence (*n* = 597) (%)
Knee	54 (15.2)	31 (12.9)	85 (14.2)
Hip	45 (12.6)	21 (8.7)	66 (11.1)
Lumbar spine	9 (2.5)	21 (8.7)	30 (5.0)
Interphalangeal joints	9 (2.5)	5 (2.1)	14 (2.3)
Cervical spine	8 (2.2)	5 (2.1)	13 (2.2)
1st metatarsophalangeal joint	7 (2.0)	2 (0.8)	9 (1.5)
Ankle	3 (0.8)	5 (2.1)	8 (1.3)
Midtarsal joints	1 (0.3)	7 (2.9)	8 (1.3)
Shoulder	6 (1.7)	2 (0.8)	8 (1.3)
1st carpometacarpal joint	4 (1.1)	3 (1.2)	7 (1.2)
Wrist	4 (1.1)	3 (1.2)	7 (1.2)
Sacroiliac joint	1 (0.3)	-	1 (0.2)
Acromioclavicular joint	1 (0.3)	-	1 (0.2)
Elbow	1 (0.3)	-	1 (0.2)

5.3.1 The Prevalence of Osteoarthritis in Relation to Age

The prevalence of a self-reported physician-diagnosis of OA was higher in GB Olympians aged 60 years and older (40.8%; 139/341), compared to those aged 50-59 years (24.3%; 35/144), and 40-49 years (14.3%; 16/112) ($P < 0.001$). The prevalence of OA was highest at the knee joint across all age categories, and the hip and the lumbar spine in those aged 50-59 years, and those aged 60 years and older (see Table 30). There was a similar prevalence of OA between all age categories at the 1st carpometacarpal joint, the elbow joint, sacroiliac joint, and the acromioclavicular joint.

Table 30: Prevalence of Osteoarthritis by Age Categories

Joint	40-49 Years (*n* = 112) (%)	50-59 Years (*n* = 144) (%)	60-97 Years (*n* = 341) (%)
Knee	6 (5.4)	12 (8.3)	67 (19.6)
Hip	2 (1.8)	11 (7.6)	53 (15.5)
Lumbar spine	1 (0.9)	6 (4.2)	23 (6.7)
Interphalangeal joints	-	3 (2.1)	11 (3.2)
Cervical spine	1 (0.9)	2 (1.4)	10 (2.9)
1st metatarsophalangeal joint	2 (1.8)	1 (0.7)	6 (1.8)
Ankle	2 (1.8)	1 (0.7)	5 (1.5)
Midtarsal joints	1 (0.9)	2 (1.4)	5 (1.5)
Shoulder	-	1 (0.7)	7 (2.1)
1st carpometocarpal joint	2 (1.8)	3 (2.1)	2 (0.6)
Wrist	-	-	7 (2.1)
Sacroiliac joint	-	-	1 (0.3)
Acromioclavicular joint	-	-	1 (0.3)
Elbow	-	-	1 (0.3)

5.3.2 The Prevalence of Osteoarthritis in Relation to Gender

The prevalence of OA among GB Olympians aged 40 years and older was reported to be similar between the sexes at the cervical spine (male: 2.2%, 8/356: female: 2.1%, 5/241), 1st carpometacarpal joint (male: 1.1%, 4/356: female: 1.2%, 3/241), wrist (male: 1.1%, 4/356: female: 1.2%, 3/241), and the interphalangeal joints (male: 2.5%, 9/356: female: 2.1%, 5/241) (see Table 29). The prevalence of OA was greater among female GB Olympians at the lumbar spine (female: 8.7%, 21/241: male: 2.5%, 9/356), midtarsal joints (female: 2.9%, 7/241: male: 0.3%, 1/356), and the ankle joint (female: 2.1%; 5/241: male: 0.8%, 3/356). The presence of OA was most prevalent among male GB Olympians at the knee (male: 15.2%, 54/356: female: 12.9%, 31/241), hip (male: 12.6%, 45/356: female: 8.7%, 21/241), and the 1st metatarsophalangeal joint (male: 2.0%, 7/356: female: 0.8%, 2/241).

5.3.3 The Prevalence of Osteoarthritis in Relation to Sport

The largest proportion of GB Olympians aged 40 years and older who replied to the Olympians questionnaire competed in athletics (23.8%; 142/597), rowing (14.4%; 86/597), swimming (10.9%; 65/597), hockey (8.5%; 51/597), canoeing (4.4%; 26/597) and cycling (4.0%; 24/597). Knee OA was more prevalent in swimming (20.0%; 13/65) and hockey (19.6%; 10/51); and lowest for canoeing (3.8%; 1/26) (see Table 31). Hip OA was greatest among those recorded as competing in hockey (15.7%; 8/51), and athletics (15.5%; 22/142); and lowest for canoeing (3.8%; 1/26). Of those with lumbar spine OA, the greatest prevalence

was in canoeing (11.5%; 3/26) and swimming (7.7%; 5/65); and lowest for cycling (0%; 0/24) (with no cases of lumbar spine OA reported).

Table 31: Prevalence of Osteoarthritis at the Hip, Knee, and the Lumbar Spine according to Sport

Sport	Hip OA (%)	Knee OA (%)	Lumbar Spine OA (%)
Athletics (*n* = 142)	22 (15.5)	23 (16.2)	8 (5.6)
Hockey (*n* = 51)	8 (15.7)	10 (19.6)	2 (3.9)
Canoeing (*n* = 26)	1 (3.8)	1 (3.8)	3 (11.5)
Cycling (*n* = 24)	1 (4.2)	3 (12.5)	-
Swimming (*n* = 65)	4 (6.2)	13 (20.0)	5 (7.7)
Rowing (*n* = 86)	10 (11.6)	6 (7.0)	2 (2.3)

5.3.4 Osteoarthritis and Injury in Great Britain's Olympians

The prevalence of self-reported physician-diagnosed OA was reported among GB Olympians aged 40 years and older who replied to the Olympian questionnaire (*n* = 605), 371 reported at least one injury (*n* = 684 total injuries), with 212 reporting no injury. There were 22 missing cases that were excluded from the analysis. In total, there were 85 athletes with knee OA, 66 athletes with hip OA, and 30 athletes with lumbar spine OA. Of the 85 athletes with knee OA, 28 had sustained at least one previous significant knee injury (*n* = 31 total knee injuries). These injuries consisted of 11 cartilage injuries, 9 sprain (injury of joint and / or ligaments), 2 dislocations, 2 ligamentous rupture, 1 fracture, 1 tendinosis / tendinopathy, 1 contusion / haematoma, and 4 other

injuries that were not specified. Among the 30 athletes with lumbar spine OA, 4 athletes had sustained at least one previous significant lumbar spine injury. The injuries consisted of two intervertebral disc injuries, one contusion, and one joint related injury. Among the 66 athletes with hip OA, 9 athletes had sustained at least one previous significant hip injury. Due to missing data, no further analysis of hip OA was undertaken.

5.4 Prevalence of Pain and Osteoarthritis in Great Britain's Olympians who Retired from Sport Early Following Injury

In total, there were 714 replies to the Olympians questionnaire. Of those who replied, 84.7% (*n* = 605) were retired from sport, and 21.8% (*n* = 132) of those retired from sport reported that they had retired early because of injury. The main locations of injuries that were reported to be responsible for retirement from sport was the lower back (25.8%), knee (25.0%), lower leg (8.3%), ankle (7.6%), Achilles tendon (6.8%), shoulder (6.8%), hip (5.3%), and thigh (5.3%). The main types of injury reported to be responsible for retirement from sport were injuries to the lumbar spine intervertebral disc (19.0%), joint sprain (injury of joint and / or ligaments) (18.2%), hyaline cartilage injury (9.1%), tendinosis / tendinopathy (9.9%), muscle injury (7.4%), osteoarthritis (5.0%), tendon rupture (3.3%) and ligamentous rupture (3.3%).

The injury rate was calculated among 689 of the 714 GB Olympians who replied to the questionnaire. The injury rate per athlete was not

significantly different between GB Olympians who had retired from sport early because of injury (1.81; 230/127), compared to those who had not been forced to retire from sport because of injury (1.18; 665/562) (*P* = 0.335). The prevalence of pain was calculated among 659 GB Olympians who had replied to the questionnaire. The prevalence of pain was higher for the GB Olympians who had retired from sport early because of injury (78.0%; 96/123), compared to those who had not been forced to retire from sport because of injury (62.3%; 334/536) (*P* = 0.002). The prevalence of OA was calculated among 597 GB Olympians aged 40 years and older. The prevalence of OA was also higher for the GB Olympians who had retired from sport early because of injury (41.7%; 48/115), compared to those who had not been forced to retire from sport because of injury (29.5%; 142/482) (*P* = 0.006).

6.0 RISK FACTORS ASSOCIATED WITH PAIN AND SELF-REPORTED PHYSICIAN-DIAGNOSED OSTEOARTHRITIS

6.1 Musculoskeletal Pain in Great Britain's Olympians

The purpose of the following data analysis was to identify in Great Britain's Olympians aged 40 years and older the individual risk factors associated with musculoskeletal pain. Three separate models of binary logistic regression were constructed to examine covariates associated with pain at the knee, hip and lumbar spine. Covariates of known clinical importance (i.e. age, body mass index and gender) were included in each model of logistic regression, irrespective of their statistical significance. Further covariates were selected based on their significance in relation to the dependent variable of interest. The steps taken to select the covariates are explained below.

6.1.1 Analysis of Knee Pain

6.1.1.1 Purposeful Selection of Covariates

A series of chi-square tests of independence were performed to determine whether or not there was an association between 14 covariates, each coded on a categorical scale, and the dependent variable - knee pain (see Table 32). In addition, independent samples t-tests were performed on four covariates that were each coded on a continuous scale. The following covariates: age, body mass index, knee injury, weight-bearing loading sports, early-life (20-29 years) GJH, comorbidities, finger nodes, lower back pain, hip pain, widespread pain and physical well-being were detected to be significantly associated

with knee pain at the 25% level (i.e. $P < 0.25$). Five covariates: gender, early-life (20-29 years) knee mal-alignment, index ring finger ratio, occupational impact sport and mental well-being were not detected to be significantly associated with knee pain ($P > 0.25$).

6.1.1.2 Fitting the Multivariable Regression Model

All covariates identified for inclusion in the univariable regression model (see Table 32), along with those of clinical relevance (i.e. age, BMI and gender), were fitted into the multivariable regression model (see Table 33). The importance of the covariates added to the multivariable regression model was assessed using the *p*-value of the Wald statistic and a traditional significance level of $P < 0.05$. Finger nodes were found to be acting as a confounder between widespread pain and knee pain. This interaction helps to explain why finger nodes were detected to be acting as a protector against knee pain. Finger nodes and widespread pain were both deleted from the model before being added, one at a time, to a revised model. Widespread pain was detected to be statistically significant and was retained in the final multivariable model. After fitting the multivariable regression model, the covariates - generalised joint hypermobility in early-life (20-29 years), comorbidities, lower back pain, hip pain and finger nodes – were also eliminated.

6.1.1.3 Refitting the Multivariable Regression Model

Covariates excluded from the multivariable regression model were added, one at a time, to a revised model, along with each of the

covariates excluded from the univariable model. Early-life (20-29 years) knee mal-alignment was significant when added to the model. The values of the estimated coefficients for previous knee injury, weight-bearing loading sports, early-life (20-29 years) knee mal-alignment, widespread pain, and physical well-being were compared to their respective values from the larger model. Neither of the coefficients changed markedly in magnitude and none of the excluded covariates were considered important in terms of providing a necessary adjustment to the variables that remained in the model. This process helped to construct the preliminary results model containing all of the essential covariates (see Table 34).

6.1.1.4 Checking for Interactions in the Main Effects Model

A list of possible interactions was constructed, and interactions among the variables in the model were assessed (Appendix V: Table 89). None of the interactions were included in the multivariable regression model because they were not statistically significant ($P < 0.05$).

6.1.1.5 Checking the Fit of the Model

The logistic regression model using eight predictors (age, BMI, gender, previous knee injury, weight-bearing loading sports, early-life knee mal-alignment (20-29 years), widespread pain and physical well-being) was able to correctly classify 78% of cases. The chi-square value for the Hosmer and Lemeshow Test (7.707, $P = 0.463$) indicated support for the fit of the final multivariable regression model ($P > 0.05$).

Table 32: Results of Fitting the Univariable Regression Knee Pain Model, *n* = 605

	Coeff.	Std.Err.	OR	95% CI	X^2	*P*
AGE	0.02	0.01	1.02	1.00, 1.03	*t* (562) = -2.07***	0.02
BMI (without outlier)	0.10	0.03	1.11	1.05, 1.16	*t* (555) = -3.60***	0.00
GENDER	0.10	0.20	1.11	0.75, 1.62	0.26*	0.61
PRIOR KNEE INJURY	0.87	0.25	2.38	1.46, 3.88	12.51*	0.00
ALIGNMENT (varus)	0.76	0.33	2.14	1.13, 4.05	0.19**	0.67
SPORT: W.B. LOADING	0.55	0.21	1.73	1.15, 2.58	7.14*	0.01
HYPERMOBILITY	0.50	0.29	1.65	0.94, 2.89	3.12*	0.08
COMORBIDITIES (≥ 2)	0.62	0.24	1.86	1.17, 2.97	6.88**	0.01
2D: 4D (Index < Ring)	0.17	0.24	1.18	0.75, 1.87	0.32**	0.57
FINGER NODES	-0.62	0.46	0.54	0.22, 1.32	1.88*	0.17
SPORT: IMPACT	-0.25	0.26	0.78	0.47, 1.30	0.91*	0.34
LOWER BACK PAIN	0.51	0.20	1.66	1.12, 2.46	6.47*	0.01
HIP PAIN	0.37	0.22	1.45	0.94, 2.24	2.86*	0.09
WIDESPREAD PAIN	0.71	0.21	2.04	1.36, 3.05	12.23*	0.001
SF-12 MCS	-0.00	0.01	1.00	0.98, 1.02	*t* (562) = 0.06***	0.95
SF-12 PCS	-0.06	0.01	0.94	0.93, 0.96	*t (562) = 5.95***	0.001

*Pearson chi-square test used for categorical variables with two levels. **Pearson linear-by-linear reported on for ordinal categorical data. ***Independent-samples t-test used for continuous data. Values in blue are significant at $P < 0.25$.

Table 33: Results of Fitting the Multivariable Regression Knee Pain Model with all Covariates Significant at the 0.25 Level in the Univariable Analysis

	Coeff.	Std.Err.	*P*	aOR	95% CI
AGE	0.01	0.01	0.45	1.01	0.99, 1.03
BMI (without outlier)	0.10	0.03	0.01	1.10	1.03, 1.18
GENDER	0.84	0.30	0.01	2.31	1.29, 4.15
PRIOR KNEE INJURY	0.97	0.30	0.001	2.62	1.45, 4.75
SPORT: W.B. LOADING	0.61	0.28	0.03	1.85	1.08, 3.17
HYPERMOBILITY	0.62	0.36	0.08	1.85	0.92, 3.72
COMORBIDITIES (≥ 2)	0.18	0.33	0.58	1.20	0.63, 2.30
FINGER NODES	-2.11	0.64	0.001	0.12	0.04, 0.42
LOWER BACK PAIN	0.10	0.38	0.79	1.11	0.53, 2.32
HIP PAIN	-0.21	0.32	0.51	0.81	0.43, 1.52
WIDESPREAD PAIN	0.84	0.37	0.02	2.33	1.13, 4.78
SF-12 PCS	-0.05	0.02	0.001	0.95	0.92, 0.98

Values in blue refer to risk factors significantly ($P < 0.05$) associated with the prevalence of knee pain.

Table 34: Results of Refitting the Multivariable Regression Knee Pain Model with all Covariates Significant at the 0.05 Level

	Coeff.	Std.Err.	*P*	aOR	95% CI
AGE	0.01	0.01	0.55	1.01	0.99, 1.03
BMI (without outlier)	0.08	0.03	0.01	1.09	1.03, 1.15
GENDER	0.49	0.25	0.05	1.63	0.99, 2.66
PRIOR KNEE INJURY	1.05	0.28	0.001	2.86	1.66, 4.94
SPORT: W.B. LOADING	0.62	0.24	0.01	1.85	1.16, 2.97
KNEE ALIGNMENT (varus)	0.80	0.37	0.03	2.23	1.08, 4.64
WIDESPREAD PAIN	0.55	0.24	0.02	1.74	1.08, 2.80
SF-12 PCS	-0.05	0.01	0.001	0.95	0.93, 0.97

Values in blue refer to risk factors significantly ($P < 0.05$) associated with the prevalence of knee pain.

6.1.1.6 Checking for Multicollinearity

The assumption of multicollinearity was not violated because the correlations between the covariates were not greater than *r* = .7 (Appendix U: Table 95). The tolerance value for each independent variable is not less than 0.10, and the variance inflation factor was not above 10 (Appendix U: Table 96) (Pallant 2007).

6.1.2 Risk Factors Associated with Knee Pain

The final multivariable regression model investigated whether or not there was a significant association between knee pain and the following covariates: age, body mass index, gender, previous knee injury, weight-bearing loading sports, early-life (20-29 years) knee mal-alignment, widespread pain and physical well-being. The results for each covariate included in the multivariable regression model are discussed below.

6.1.2.1 Constitutional Factors

6.1.2.1.1 Age

The mean age of GB Olympians reporting that they had experienced recent knee pain (*M* = 65.64 $\pm$ 12.73 years) was greater than those with no recent history (*M* = 63.00 $\pm$ 13.52 years). The crude odds ratio indicated a significant association between recent knee pain and a one-unit increase in age [OR 1.02; 95% CI, 1.00-1.03] (see Table 35). This association was, however, no longer significant after adjustment had been made for the remaining seven covariates [aOR 1.01; 95% CI, 0.99-1.03].

Table 35: Prevalence of Knee Pain in Relation to Constitutional Factors (Continuous Independent Variables)

	Prevalence of knee pain (Mean + SD)		Odds ratio (95% confidence interval)	
	Yes	No	Crude	Adjusted
Age: (Years)	65.64 ± 12.73	63.00 ± 13.52	1.02 (1.00, 1.03)	1.01 (0.99, 1.03)

Values in blue refer to risk factors significantly ($P < 0.05$) associated with the prevalence of knee pain.

The results of the quartile design variable analysis of the scale of age (see Table 36) are plotted in Figure 21. This plot illustrates a quadratic trend with a linear increase in the log-odds for knee pain from approximately 46 years of age until it peaks at 76. The trend then changes direction and declines with increasing age, but remains significant after approximately 59 years of age. Despite the log-odds demonstrating a non-linear relationship between age and recent knee pain, there was no significant association detected when choosing to categorize age into: 40-59 years and older than 59 years [OR 1.46; 95% CI, 0.99-2.15; aOR 1.16; 95% CI, 0.70-1.91].

Table 36: Results of the Quartile Design Variable Analysis of the Scale of Age

Quartile	1	2	3	4
Range	$x \leq 54$	$55 \leq x \leq 68$	$69 \leq x \leq 82$	$83 \leq x \leq 97$
Midpoint	47	61.5	75.5	90
Coeff.	0.0	1.24	1.88	1.30
95% CI		0.75, 2.05	1.15, 3.08	0.61, 2.77

Values in blue refer to quartiles significantly ($P < 0.05$) associated with the prevalence of knee pain.

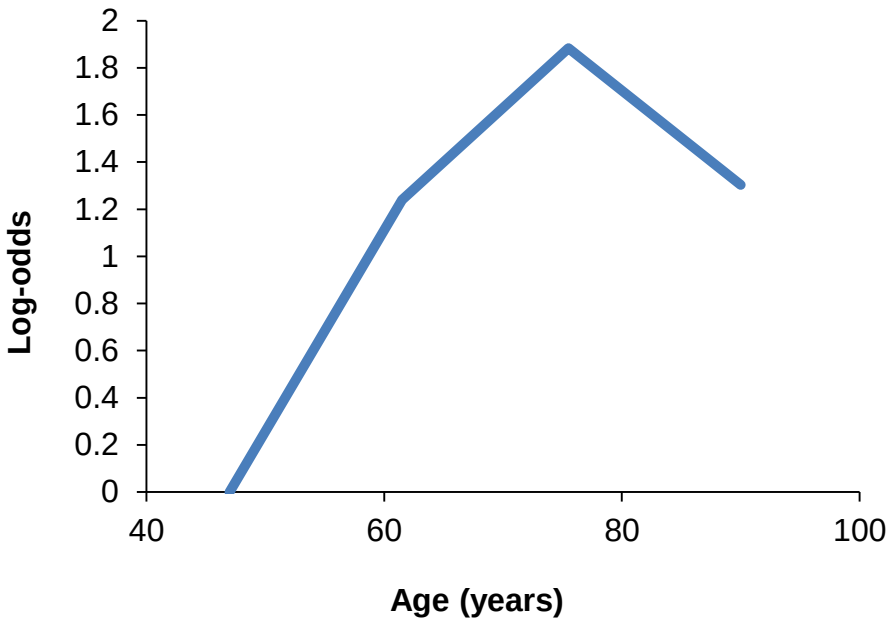


Figure 21: Plot of Estimated Logistic Regression Coefficients for the Quartile Design Variables versus Appropriate Quartile Midpoints of Age in Relation to Knee Pain

6.1.2.1.2 Body Mass Index

The mean BMI in GB Olympians reporting a recent history of knee pain (see Table 35) was marginally greater (*M* = 25.94 ± 4.70 kg/m^2) than those without (*M* = 24.40 ± 3.38 kg/m^2). Of those with knee pain, the mean BMI was within the limits of the World Health Organisation (2004) overweight category (≥ 25, < 30 kg/m^2). The mean BMI in the no recent history of knee pain group was within the limits of the normal BMI category (< 25 kg/m^2). The crude odds ratio of GB Olympians reporting recent knee pain was detected to be significantly associated with a one-unit increase in body mass index (kg/m^2) [OR 1.11; 95% CI, 1.05-1.16] (see Table 37). This significant association was confirmed following the adjustment for the remaining seven covariates [aOR 1.09; 95% CI, 1.03-1.15].

Table 37: Prevalence of Knee Pain in Relation to Constitutional Factors (Continuous Independent Variables)

	Prevalence of knee pain (Mean + SD)		Odds ratio (95% confidence interval)	
	Yes	No	Crude	Adjusted
BMI: (kg/m^2)	25.94 ± 4.70	24.40 ± 3.38	1.11 (1.05, 1.16)	1.09 (1.03, 1.15)

Values in blue refer to risk factors significantly (*P* < 0.05) associated with the prevalence of knee pain.

The results of the quartile design variable analysis of the scale of BMI (see Table 38) are plotted in Figure 22. This plot illustrates a quadratic trend with a linear increase in the log-odds for knee pain from approximately 21 kg/m^2 until it peaks at 34 kg/m^2. The trend then declines with increasing BMI, but remains significant. The log-odds for knee pain are shown to be significant after approximately 27.5 kg/m^2. There was no significant association detected when choosing to categorise BMI into: under / normal weight (< 25.00 kg/m^2) and overweight (≥ 25.00 < 30.00 kg/m^2) [OR 1.04; 95% CI, 0.67-1.61; aOR 1.04; 95% CI, 0.62-1.74]. There was, however, a significant association detected between knee pain and the BMI category of obese (≥ 30.00 kg/m^2) [OR 4.54; 95% CI, 2.49-8.28; aOR 3.78; 95% CI, 1.89-7.57].

Table 38: Results of the Quartile Design Variable Analysis of the Scale of Body Mass Index

Quartile	1	2	3	4
Range	$x \leq$ 24.21	24.22 $\leq x \leq$ 30.79	30.80 $\leq x \leq$ 37.36	37.37 $\leq x \leq$ 43.94
Midpoint	20.92	27.51	34.08	40.66
Coeff.	0.0	1.02	4.90	4.47
95% CI		0.68, 1.54	2.29, 10.49	0.98, 20.53

Values in blue refer to quartiles significantly ($P < 0.05$) associated with the prevalence of knee pain.

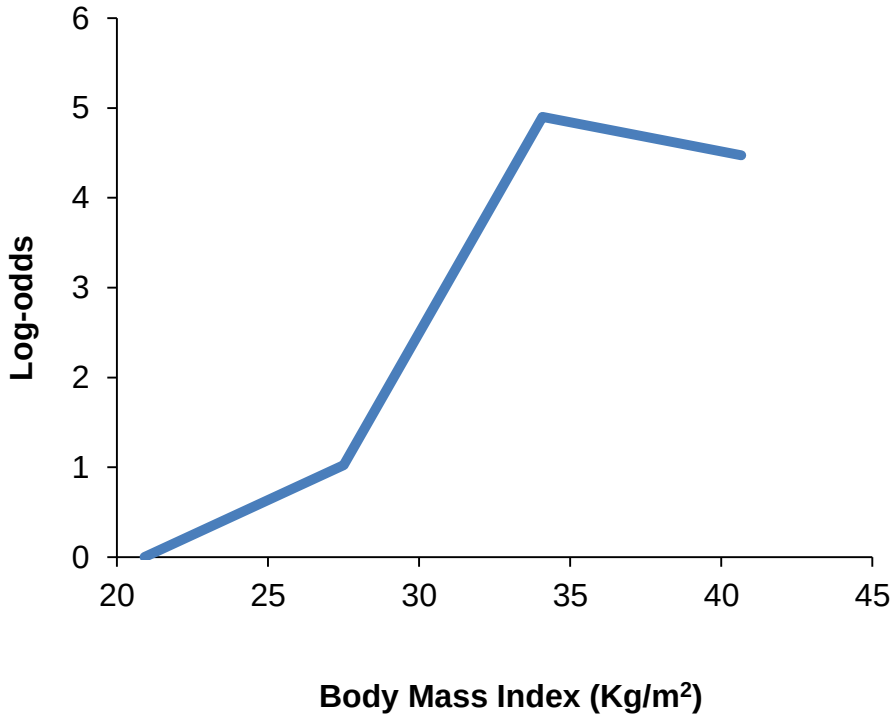


Figure 22: Plot of Estimated Logistic Regression Coefficients for the Quartile Design Variables versus Appropriate Quartile Midpoints of Body Mass Index in Relation to Knee Pain

6.1.2.1.3. Gender

The prevalence of knee pain was similar between gender (see Table 39), with 25% (86/340) of males and 27% (61/224) of females complaining of a recent history of knee pain. The crude odds ratio of females reporting knee pain was not significantly different from that of male GB Olympians [OR 1.11; 95% CI, 0.75-1.62]. This was also confirmed following the adjustment for the remaining seven covariates in the multivariable regression model [aOR 1.63; 95% CI, 0.99-2.66]. Yet the gender covariate appeared to remain clinically important with its

significance value almost reaching five per cent (*P* = 0.053).

Table 39: Prevalence of Knee Pain in Relation to Constitutional Factors (Categorical Independent Variable)

Constitutional factors	Prevalence rate (%)		Odds ratio (95% confidence interval)	
			Crude	Adjusted
Gender:				
Male	86/340	(25%)	**1**	**1**
Female	61/224	(27%)	1.11 (0.75, 1.62)	1.63 (0.99, 2.66)

6.1.2.2 Biomechanical Factors

6.1.2.2.1 Knee Injury

Of the 83 GB Olympians with a prior history of a significant knee injury, 41% (34/83) reported knee pain. Among the 456 GB Olympians without a history of a significant knee injury, 23% (103/456) complained of knee pain (see Table 40). A previous history of a significant knee injury was detected to be significantly associated with a recent history of knee pain [OR 2.38; 95% CI, 1.46-3.88], and this was confirmed after adjustment for the remaining covariates in the multivariable regression model [aOR 2.86; 95% CI, 1.66-4.94].

Table 40: Prevalence of Knee Pain in Relation to Biomechanical Factors

Biomechanical factors	Prevalence rate (%)		Odds ratio (95% confidence interval)	
			Crude	Adjusted
Knee injury:				
No	103/456	(23%)	**1**	**1**
Yes	34/83	(41%)	2.38 (1.46, 3.88)	2.86 (1.66, 4.94)
Occupational athletic activity:				
Non-weight-bearing	44/221	(20%)	**1**	**1**
Weight-bearing	103/343	(30%)	1.73 (1.15, 2.58)	1.85 (1.16, 2.97)
Knee angulation in 20's:				
Normal	123/488	(25%)	**1**	**1**
Varus	18/43	(42%)	2.14 (1.13, 4.05)	2.23 (1.08, 4.64)
Valgus	2/17	(12%)	0.40 (0.09, 1.76)	0.11 (0.01, 1.01)

Values in blue refer to risk factors significantly ($P < 0.05$) associated with the prevalence of knee pain.

6.1.2.2.2 Weight-Bearing Loading Sports

The prevalence of knee pain in GB Olympians who had competed in a weight-bearing loading sport was 30% (103/343), compared to 20% (44/221) in those who had competed in a non-weight-bearing loading sport (see Table 40). The crude odds ratio confirms that the risk of knee

pain was significantly greater in those who had competed in a weight-bearing loading sport [OR 1.73; 95% CI, 1.15-2.58]. This was confirmed further following the adjustment for the remaining seven covariates [aOR 1.85; 95% CI, 1.16-2.97].

6.1.2.2.3 Knee Angulation

Of the 43 GB Olympians who reported early-life (20-29 years of age) varus knee mal-alignment, 42% (18/43) reported a recent history of knee pain compared to 12% (2/17) and 25% (123/488) of GB Olympians with valgus and normal knee alignment, respectively (see Table 40). The risk of knee pain was significantly greater in those with early-life (20-29 years) varus knee mal-alignment [OR 2.14; 95% CI, 1.13-4.05]. This association was confirmed at traditional levels ($P < 0.05$) following adjustment for the remaining seven covariates [aOR 2.23; 95% CI, 1.08-4.64]. Early-life (20-29 years) valgus knee mal-alignment was not detected to be significantly associated with knee pain [OR 0.40; 95% CI, 0.09-1.76], and this was confirmed following adjustment [aOR 0.11; 95% CI, 0.01-1.01].

6.1.2.3 Other Factors

6.1.2.3.1 Widespread Pain

The prevalence of knee pain was 37% (56/153) and 22% (90/408) in GB Olympians with and without widespread pain, respectively (see Table 41). A recent history of widespread pain was detected to be significantly associated with a recent history of knee pain [OR 2.04;

95% CI, 1.36-3.05], and this was confirmed after adjustment for the remaining covariates [aOR 1.74; 95% CI, 1.08-2.80].

Table 41: Prevalence of Knee Pain in Relation to Widespread Pain

		Prevalence rate (%)	Odds ratio (95% confidence interval)	
			Crude	Adjusted
Widespread pain:				
No	90/408	(22%)	**1**	**1**
Yes	56/153	(37%)	2.04 (1.36, 3.05)	1.74 (1.08, 2.80)

Values in blue refer to risk factors significantly ($P < 0.05$) associated with the prevalence of knee pain.

6.1.2.3.2 Physical Well-Being

The mean SF-12 psychological summary score was similar in those with a recent history of knee pain (53.78 $\pm$ 8.31), compared to those without (53.83 $\pm$ 7.40). The mean SF-12 physical summary score was, however, smaller in those with a recent history of knee pain (45.83 $\pm$ 10.64), compared to those without (51.67 $\pm$ 9.03). There was no significant relationship detected between the psychological component SF-12 summary score and knee pain [OR 1.00; 95% CI, 0.98-1.02]. This covariate was therefore eliminated from the final model. As the physical component SF-12 summary score increased, the odds of experiencing recent knee pain were found to be significantly lower [OR 0.94; 95% CI, 0.93-0.96]. This association was confirmed following the

adjustment for the remaining seven covariates [aOR 0.95; 95% CI, 0.93-0.97] (see Table 42).

Table 42: Quality of Life and the Prevalence of Knee Pain

QOL	Prevalence of knee pain (mean + SD)		Adjusted odds ratio (95% confidence interval)	
	Yes	No	Crude	Adjusted
SF12:				
Psychological	53.78 ± 8.31	53.83 ± 7.40	1.00 (0.98, 1.02)	N/a
Physical	45.83 ± 10.64	51.67 ± 9.03	0.94 (0.93, 0.96)	0.95 (0.93, 0.97)

Values in blue refer to risk factors significantly ($P < 0.05$) associated with the prevalence of knee pain.

6.1.3 Analysis of Hip Pain

6.1.3.1 Purposeful Selection of Covariates

A series of chi-square tests of independence were performed to determine whether there was a significant association between 13 covariates and hip pain (see Table 43). The covariates - hip injury, weight-bearing loading sports, comorbidities and physical well-being were detected to be significantly associated with hip pain at the 25% level (i.e. $P < 0.25$). Nine covariates – age, BMI, gender, early-life (20-29 years) varus knee mal-alignment, generalised joint hypermobility in early-life (20-29 years), index ring finger ratio, finger nodes, impact sport and mental well-being - were not detected to be significantly associated with hip pain ($P > 0.25$).

6.1.3.2 Fitting the Multivariable Regression Model

All covariates identified for inclusion in the univariable regression model, along with those of clinical relevance (age, body mass index and gender), were fitted into the multivariable regression model (see Table 44). The importance of the covariates added to the multivariable regression model was assessed using the *p*-value of the Wald statistic and a traditional significance level of $P < 0.05$.

6.1.3.3 Refitting the Multivariable Regression Model

Covariates excluded from the multivariable regression model were added, one at a time, to a revised model, along with each of the covariates excluded from the univariable model. The values of the estimated coefficients for previous hip injury, weight-bearing loading sports and physical well-being were compared to their respective values from the larger model. Neither of the coefficients changed markedly in magnitude and none of the excluded covariates were considered important in terms of providing a necessary adjustment for the variables that remained in the model. The value for the covariate - comorbidities - was no longer statistical significant ($P < 0.05$) in the multivariable regression model, and it was dropped from the final model. This process helped to construct the preliminary results model, which contained all the essential covariates (see Table 45).

Table 43: Results of Fitting the Univariable Regression Hip Pain Model, *n* = 563

	Coeff.	Std.Err.	OR	95% CI	X^2	*P*
AGE	0.01	0.01	1.01	0.99, 1.02	*t* (561) = -1.08***	0.28
BMI (without outlier)	0.03	0.03	1.03	0.98, 1.08	*t* (554) = -0.97***	0.33
GENDER	-0.05	0.21	0.95	0.64, 1.43	0.06*	0.82
PRIOR HIP INJURY	1.75	0.54	5.76	2.01, 16.55	13.27*	0.001
ALIGNMENT (varus)	0.06	0.38	1.06	0.51, 2.23	0.41**	0.52
SPORT: W.B. LOADING	0.55	0.22	1.73	1.13, 2.66	6.43*	0.01
HYPERMOBILITY	-0.16	0.33	0.85	0.45, 1.61	0.24*	0.62
COMORBIDITIES (≥ 2)	0.37	0.13	1.44	1.12, 1.85	8.34**	0.004
2D: 4D (Index < Ring)	0.17	0.25	1.19	0.72, 1.94	0.19**	0.66
FINGER NODES	-0.21	0.43	0.81	0.35, 1.89	0.24**	0.63
SPORT: IMPACT	-0.29	0.28	0.75	0.43, 1.28	1.12*	0.29
SF-12 MCS	-0.01	0.01	0.99	0.96, 1.01	*t (561) = 1.03***	0.30
SF-12 PCS	-0.04	0.01	0.96	0.94, 0.98	*t (186) = 4.16****	0.001

Pearson chi-square test used for categorical variables with two levels. **Pearson linear-by-linear reported on for ordinal categorical data. ***Independent-samples t-test used for continuous data. Values in blue refer to risk factors significantly (*P* < 0.25) associated with the prevalence of hip pain.

Table 44: Results of Fitting the Multivariable Regression Hip Pain Model with all Covariates Significant at the 0.25 Level in the Univariable Analysis

	Coeff.	Std.Err.	*P*	aOR	95% CI
AGE	-0.02	0.01	0.08	0.98	0.96, 1.00
BMI (without outlier)	0.001	0.03	0.96	1.00	0.95, 1.06
GENDER	-0.12	0.25	0.62	0.89	0.54, 1.44
PRIOR HIP INJURY	1.76	0.57	0.002	5.82	1.92, 17.71
SPORT: W.B. LOADING	0.59	0.24	0.01	1.80	1.13, 2.88
COMORBIDITIES (≥ 2)	0.55	0.30	0.07	1.74	0.96, 3.13
SF-12 PCS	-0.05	0.01	0.001	0.94	0.92, 0.96

Values in blue refer to risk factors significantly ($P < 0.05$) associated with the prevalence of hip pain.

Table 45: Results of Refitting the Multivariable Regression Hip Pain Model with all Covariates Significant at the 0.05 Level

	Coeff.	Std.Err.	*P*	aOR	95% CI
AGE	-0.01	0.01	0.19	0.99	0.97, 1.01
BMI (without outlier)	0.01	0.03	0.76	1.01	0.95, 1.07
GENDER	-0.11	0.25	0.65	0.89	0.55, 1.45
PRIOR HIP INJURY	1.65	0.56	0.003	5.20	1.74, 15.53
SPORT: W.B. LOADING	0.59	0.24	0.01	1.81	1.14, 2.88
SF-12 PCS	-0.05	0.01	0.001	0.95	0.93, 0.97

Values in blue refer to risk factors significantly ($P < 0.05$) associated with the prevalence of hip pain.

6.1.3.4 Checking for Interactions in the Main Effects Model

A list of possible interactions was constructed. From this list, interactions among the variables in the model were assessed (Appendix T: Table 90). None of the interactions was included in the multivariable regression model; they were not statistically significant ($P < 0.05$).

6.1.3.5 Checking the Fit of the Model

The logistic regression model using six predictors (age, body mass index, gender, previous hip injury, weight-bearing loading sports and physical well-being) was able to classify correctly 78% of cases. The chi-square value for the Hosmer and Lemeshow Test (10.636, $P = 0.223$) indicated support for the fit of the final multivariable regression model ($P > 0.05$).

6.1.3.6 Checking for Multicollinearity

The assumption of mulitcollinearity was not violated because the correlations between the covariates were not greater than $r = .7$ (Appendix U: Table 97). The tolerance value for each independent variable is not less than 0.10, and the variance inflation factor was not above 10 (Appendix U: Table 98) (Pallant 2007).

6.1.4 Risk Factors Associated with Hip Pain

The final multivariable regression model investigated whether or not there was a significant association between hip pain and the following six covariates: age, body mass index, gender, previous hip injury,

weight-bearing loading sports and physical well-being. The results for each covariate included in the multivariable regression model are discussed below.

6.1.4.1 Constitutional Factors

6.1.4.1.1 Age

The mean age of GB Olympians who reported they had experienced hip pain recently (*M* = 64.81 ± 12.85 years) was greater than those with no recent history (*M* = 63.35 ± 13.51 years) (see Table 46). The crude odds ratio did not detect a significant association between recent hip pain and a one-unit increase in age [OR 1.01; 95% CI, 0.99-1.02]. This was confirmed following the adjustment for the remaining five covariates in the multivariable regression model [aOR 0.99; 95% CI, 0.97-1.01].

Table 46: Prevalence of Hip Pain in Relation to Constitutional Factors (Continuous Independent Variables)

	Prevalence of Hip Pain (Mean ± SD)		Odds ratio (95% confidence interval)	
	Yes	No	Crude	Adjusted
Age: (Years)	64.81 ± 12.85	63.35 ± 13.51	1.01 (0.99, 1.02)	0.99 (0.97, 1.01)

The results of the quartile design variable analysis of the scale of age (see Table 47) are plotted in Figure 23. This plot illustrates a quadratic trend with a linear increase in the log-odds for hip pain from approximately 46 years of age until it peaks at 75 years. The trend then changes direction and declines with increasing age. The log-odds for hip pain are shown to be significant between approximately 62 and 80 years of age. Those who survived beyond 80 years were less likely to report a recent history of hip pain. Despite the log-odds demonstrating a non-linear relationship between age and recent hip pain, there was no significant association detected when choosing to categorise age into: 40-59 years and older than 59 years [OR 1.41; 95% CI, 0.94-2.13; aOR 0.94; 95% CI, 0.57-1.54].

Table 47: Results of the Quartile Design Variable Analysis of the Scale of Age

Quartile	1	2	3	4
Range	$x \leq 54$	$55 \leq x \leq 68$	$69 \leq x \leq 82$	$83 \leq x \leq 97$
Midpoint	47	61.5	75.5	90
Coeff.	0.0	1.07	1.20	0.75
95% CI		0.64, 1.77	0.72, 2.00	0.32, 1.75

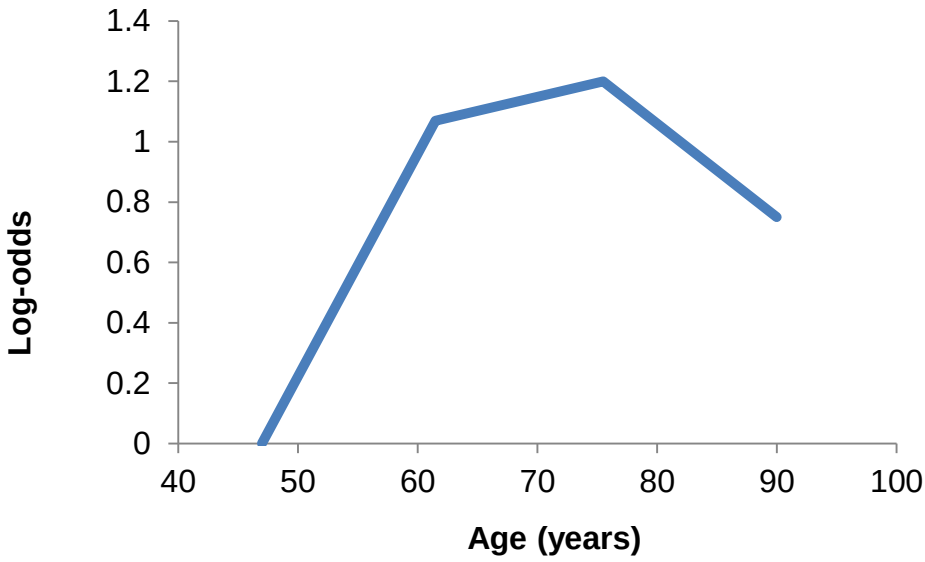


Figure 23: Plot of Estimated Logistic Regression Coefficients for the Quartile Design Variables versus Appropriate Quartile Midpoints of Age in Relation to Hip Pain

6.1.4.1.2 Body Mass Index

The mean BMI in GB Olympians reporting a recent history of hip pain (see Table 34) was slightly higher (*M* = 25.10 $\pm$ 4.27 kg/m^2) than those without (*M* = 24.73 $\pm$ 3.63 kg/m^2). Of those with hip pain, the mean BMI was within the limits of the World Health Organisation (2004) overweight BMI category ($\geq$ 25, < 30 kg/m^2). The mean BMI of those without a recent history hip pain was within the limits of the normal BMI category (< 25 kg/m^2). The crude odds ratio of GB Olympians reporting recent hip pain was not detected to be significantly associated with a one-unit increase in body mass index (kg/m^2) [OR 1.03; 95% CI, 0.98-1.08] (see Table 48). This was confirmed following the adjustment for the remaining five covariates [aOR 1.01; 95% CI, 0.95-1.07].

Table 48: Prevalence of Hip Pain in Relation to Constitutional Factor (Continuous Independent Variables)

	Prevalence of Hip Pain (Mean ± SD)		Odds ratio (95% confidence interval)	
	Yes	No	Crude	Adjusted
BMI: (kg/m^2)	25.10 ± 4.27	24.73 ± 3.63	1.03 (0.98, 1.08)	1.01 (0.95, 1.07)

The association between BMI and hip pain was shown to be a non-linear relationship. This is reflected by the results of the quartile design variable analysis of the scale of BMI (see Table 49) that are plotted in Figure 24. A quadratic trend is illustrated, with a linear increase in the log-odds for hip pain from approximately 21 kg/m^2 until it peaks at 34 kg/m^2. The trend then changes direction and declines to approximately 42 kg/m^2. The log-odds for recent hip pain remain significant after approximately 28 kg/m^2. There was no significant association detected when choosing to categorize BMI into: under / normal weight (< 25.00 kg/m^2), overweight (≥ 25.00 < 30.00 kg/m^2) - [OR 0.95; 95% CI, 0.61-1.49; aOR 1.09; 95% CI, 0.66-1.79], and obese (≥ 30.00 kg/m^2) [OR 1.53; 95% CI, 0.80-2.90; aOR 1.15; 95% CI, 0.57-2.32].

Table 49: Results of the Quartile Design Variable Analysis of the Scale of Body Mass Index

Quartile	1	2	3	4
Range	$x \leq 24.21$	$24.22 \leq x \leq 30.79$	$30.80 \leq x \leq 37.36$	$37.37 \leq x \leq 43.94$
Midpoint	20.92	27.51	34.08	40.66
Coeff.	0.0	0.89	1.80	1.37
95% CI		0.59, 1.36	0.82, 3.93	0.26, 7.24

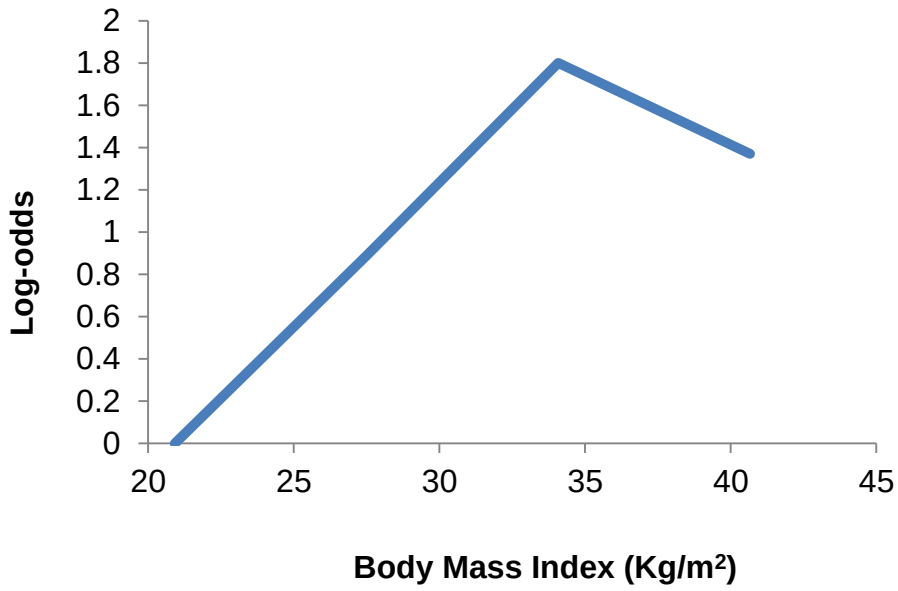


Figure 24: Plot of Estimated Logistic Regression Coefficients for the Quartile Design Variables versus Appropriate Quartile Midpoints of Body Mass Index in Relation to Hip Pain

6.1.4.1.3 Gender

The prevalence of hip pain was similar between gender with 23% (77/339) of males and 22% (49/224) of females complaining of recent

hip pain. Gender was not detected to be significantly associated with hip pain (OR 0.95; 95% CI, 0.64-1.43), and this was confirmed following the adjustment for the remaining five covariates [aOR 0.89; 95% CI, 0.55-1.45] (see Table 50).

Table 50: Prevalence of Hip Pain in Relation to Constitutional Factors (Categorical Independent Variables)

Biomechanical Factors	Prevalence rate (%)		Odds ratio (95% confidence interval)	
			Crude	Adjusted
Gender:				
Male	77/339	(23%)	**1**	**1**
Female	49/224	(22%)	0.95 (0.64, 1.43)	0.89 (0.55, 1.45)

6.1.4.2 Biomechanical Factors

6.1.4.2.1 Hip Injury

The prevalence of hip pain was 21% (108/523) in GB Olympians who had no prior history of a significant hip injury, compared to 60% (9/15) in those with a previous history of a significant hip injury (see Table 51). A previous history of a significant hip injury was significantly associated with hip pain [OR 5.76; 95% CI, 2.01-16.55]. This was confirmed after adjustment for the remaining covariates in the multivariable regression model [aOR 5.20; 95% CI, 1.74-15.53].

6.1.4.2.2 Weight-Bearing Loading Sports

The prevalence of hip pain in GB Olympians who had competed in a weight-bearing loading sport was 26% (89/343), compared to 17% (37/220) in those who had competed in a non-weight-bearing loading sport (see Table 51). The crude OR confirms that the risk of experiencing hip pain recently was significantly greater in those who had competed in a weight-bearing loading sport [OR 1.73; 95% CI, 1.13-2.66]. This remained significant following the adjustment for the remaining five covariates in the multivariable regression model [aOR 1.81; 95% CI, 1.14-2.88].

Table 51: Prevalence of Hip Pain in Relation to Biomechanical Factors

Biomechanical factors	Prevalence rate (%)		Odds ratio (95% confidence interval)	
			Crude	Adjusted
Hip injury:				
No	108/523	(21%)	**1**	**1**
Yes	9/15	(60%)	5.76 (2.01, 16.55)	5.20 (1.74, 15.53)
Occupational athletic activity:				
Non-weight-bearing	37/220	(17%)	**1**	**1**
Weight-bearing	89/343	(26%)	1.73 (1.13, 2.66)	1.81 (1.14, 2.88)

Values in blue refer to risk factors significantly associated with the prevalence of hip pain.

6.1.4.3 Other Factors

6.1.4.3.1 Physical Well-Being

The mean SF-12 psychological summary score was similar in those with a recent history of hip pain (53.19 ± 7.71), compared to those without (53.99 ± 7.63). The mean SF-12 physical summary score was, however, smaller in those with a recent history of hip pain (46.79 ± 10.53), compared to those without (51.12 ± 9.39). There was no relationship detected between the psychological component SF-12 summary score and hip pain [OR 0.99; 95% CI, 0.96-1.01] (see Table 52), and this covariate was omitted from the final analysis. As the physical component SF-12 summary score increased, the odds of having hip pain was found to be significantly lower [OR 0.96; 95% CI, 0.94-0.98]. This significant association was confirmed after adjustment for the remaining five covariates [aOR 0.94; 95% CI, 0.92-0.96].

Table 52: Quality of Life and the Prevalence of Hip Pain

QOL	Prevalence of hip pain (Mean + SD)		Odds ratio (95% confidence interval)	
	Yes	No	Crude	Adjusted
SF12:				
Psychological	53.19 ± 7.71	53.99 ± 7.63	0.99 (0.96, 1.01)	N/a
Physical	46.79 ± 10.53	51.12 ± 9.39	0.96 (0.94, 0.98)	0.94 (0.92, 0.96)

Values in blue refer to risk factors significantly associated with the prevalence of hip pain.

6.1.5 Analysis of Lumbar Spine Pain

6.1.5.1 Purposeful Selection of Covariates

A series of chi-square tests of independence were performed to determine whether there was an association between 12 covariates and lumbar spine pain (see Table 53). Six covariates - age, BMI, lumbar spine injury, finger nodes, impact sport and physical well-being - were detected to be significantly associated with lumbar spine pain at the 25% level (i.e. $P < 0.25$). Six covariates - gender, weight-bearing loading sports, generalised joint hypermobility in early-life (20-29 years), comorbidities, index ring finger ratio and mental well-being - were not detected to be significantly associated with lumbar spine pain ($P > 0.25$).

6.1.5.2 Fitting the Multivariable Regression Model

All covariates identified for inclusion in the univariable regression model, along with those of clinical relevance, were fitted into the multivariable regression model (see Table 54). The importance of those covariates which had been added to the multivariable regression model were assessed using the *p*-value of the Wald statistic and a traditional significance level of $P < 0.05$. The covariate - impact sport - did not contribute to the model significantly and was eliminated. A new smaller model was then fitted (see Table 55). The finger nodes covariate was no longer statistically significant ($P < 0.05$) in the multivariable regression model, yet it remained in the model because it was shown to be important by its significance value of $P = 0.053$.

6.1.5.3 Refitting the Multivariable Regression Model

Covariates excluded from the multivariable regression model were added, one at a time, to the revised model, along with each of the covariates excluded from the univariable model. The values of the estimated coefficients for previous lumbar spine injury, finger nodes and physical well-being were compared to their respective values from the larger model. Neither of the coefficients changed markedly in magnitude and none of the excluded covariates was considered important in terms of providing a necessary adjustment of the effect of the variables that remained in the model. The remaining covariates were fitted into the preliminary results model, which contained all of the essential covariates (see Table 55).

6.1.5.4 Checking for Interactions in the Main Effects Model

A list of possible interactions was constructed. From this list, interactions among the variables in the model were assessed (Appendix T: Table 91). None of the interactions was included in the multivariable regression model; they were not statistically significant ($P < 0.05$).

6.1.5.5 Checking the Fit of the Model

The logistic regression model using six predictors (age, body mass index, gender, previous hip injury, finger nodes and physical well-being) was able to classify correctly 73% of cases. The chi-square value for the Hosmer and Lemeshow Test (8.232, $P = 0.411$) indicated support for the fit of the final multivariable regression model ($P > 0.05$).

Table 53: Results of Fitting the Univariable Logistic Regression Lumbar Spine Pain Model, *n* = 564

	Coeff.	Std.Err.	OR	95% CI	X^2	*P*
AGE	-0.01	0.01	0.99	0.97, 1.00	*t (562) = 1.99***	0.047
BMI (without outlier)	0.05	0.02	1.05	1.00, 1.10	*t (556) = -2.54***	0.01
GENDER	0.10	0.18	1.10	0.77, 1.58	0.29*	0.59
PRIOR L.SPINE INJURY	0.995	0.23	2.71	1.73, 4.24	19.76*	0.001
SPORT: W.B. LOADING	-0.03	0.19	0.97	0.68, 1.40	0.03*	0.87
HYPERMOBILITY	0.02	0.28	1.02	0.59, 1.77	0.004*	0.95
COMORBIDITIES (≥ 2)	0.08	0.11	1.09	0.87, 1.35	0.54**	0.46
2D: 4D (Index < Ring)	-0.07	0.21	0.93	0.61, 1.41	0.15**	0.70
FINGER NODES	0.77	0.34	2.16	1.10, 4.23	5.26*	0.02
SPORT: IMPACT	-0.71	0.26	0.49	0.29, 0.82	7.49*	0.01
SF-12 MCS	-0.01	0.01	0.99	0.97, 1.01	*t (562) = 0.95***	0.34
SF-12 PCS	-0.04	0.01	0.96	0.94, 0.98	*t (317) = 4.73***	0.001

Pearson chi-square test used for categorical variables with two levels. **Pearson linear-by-linear reported on for ordinal categorical data. ***Independent-samples t-test used for continuous data. Values in blue refer to risk factors significantly ($P < 0.05$) associated with the prevalence of lumbar spin pain.

Table 54: Results of Fitting the Multivariable Regression Lumbar Spine Pain Model with all Covariates Significant at the 0.25 Level in the Univariable Analysis

	Coeff.	Std.Err.	*P*	aOR	95% CI
AGE	-0.04	0.01	0.001	0.96	0.95, 0.98
BMI (without outlier)	0.03	0.03	0.31	1.03	0.98, 1.08
GENDER	-0.51	0.23	0.03	0.60	0.38, 0.95
PRIOR L. SPINE INJURY	0.93	0.25	0.001	2.53	1.57, 4.10
FINGER NODES	0.76	0.38	0.048	2.14	1.01, 4.53
IMPACT SPORT	-0.54	0.29	0.06	0.58	0.33, 1.02
SF-12 PCS	-0.06	0.01	0.001	0.94	0.92, 0.96

Values in blue refer to risk factors significantly ($P < 0.05$) associated with the prevalence of lumbar spin pain.

Table 55: Results of Refitting the Multivariable Regression Lumbar Spine Pain Model with all Covariates Significant at the 0.05 Level

	Coeff.	Std.Err.	*P*	aOR	95% CI
AGE	-0.04	0.01	0.001	0.96	0.95, 0.98
BMI (without outlier)	0.02	0.03	0.36	1.03	0.97, 1.08
GENDER	-0.44	0.23	0.06	0.64	0.41, 1.01
PREVIOUS L. SPINE INJURY	0.96	0.25	0.001	2.61	1.62, 4.22
FINGER NODES	0.74	0.38	0.05	2.09	0.99, 4.41
SF-12 PCS	-0.05	0.01	0.001	0.94	0.92, 0.96

Values in blue refer to risk factors significantly ($P < 0.05$) associated with the prevalence of lumbar spin pain.

6.1.5.6 Checking for Multicollinearity

The assumption of multicollinearity was not violated because the correlations between the covariates were not greater than $r = .7$ (Appendix U: Table 99). The tolerance value for each independent variable was not less than 0.10, and the variance inflation factor was not above 10 (Appendix U: Table 100) (Pallant 2007).

6.1.6 Risk Factors Associated with Lumbar Spine Pain

The final multivariable regression model investigated whether or not there was a significant association between lumbar spine pain and the following six covariates: age, body mass index, gender, previous lumbar spine injury, finger nodes and physical well-being. The results for each covariate included in the multivariable regression model are discussed below.

6.1.6.1 Constitutional Factors

6.1.6.1.1 Age

The mean age of GB Olympians reporting that they had experienced lumbar spine pain recently ($M = 62.05 \pm 12.86$ years) was lower than those without a recent history of lumbar spine pain ($M = 64.44 \pm 13.53$ years) (see Table 56). The crude odds ratio did not detect a significant association between recent lumbar spine pain and a one-unit decrease in age [OR 0.99; 95% CI, 0.97-1.00]. However, after adjusting for the remaining five covariates in the multivariable regression model, lumbar spine pain was detected to be significantly associated with a one-unit

decrease in age [aOR 0.96; 95% CI, 0.95-0.98].

Table 56: Prevalence of Lumbar Spine Pain in Relation to Constitutional Factors (Continuous Independent Variables)

	Prevalence of Lumbar Spine Pain (Mean ± SD)		Odds ratio (95% confidence interval)	
	Yes	No	Crude	Adjusted
Age: (Years)	62.05 ± 12.86	64.44 ± 13.53	0.99 (0.97, 1.00)	0.96 (0.95, 0.98)

Values in blue refer to risk factors significantly ($P < 0.05$) associated with the prevalence of lumbar spine pain.

The results of the quartile design variable analysis of the scale of age (see Table 57) are plotted in Figure 25. This plot illustrates a quadratic trend with a linear increase in the log-odds for lumbar spine pain from approximately 46 years of age until it peaks at 76 years. The trend then changes direction and declines with increasing age. Despite the log-odds demonstrating a non-linear relationship between age and recent lumbar spine pain, there was no significant association detected when choosing to categorise age into: 40-59 years and older than 59 years [OR 0.80; 95% CI, 0.56-1.14]. However, there was a significant association following adjustment for the remaining five covariates. Those aged 60 years and older were less likely to report lumbar spine pain [aOR 0.50; 95% CI, 0.32-0.79].

Table 57: Results of the Quartile Design Variable Analysis of the Scale of Age

Quartile	1	2	3	4
Range	$x \leq 54$	$55 \leq x \leq 68$	$69 \leq x \leq 82$	$83 \leq x \leq 97$
Midpoint	47	61.5	75.5	90
Coeff.	0.0	0.66	0.81	0.28
95% CI		0.42, 1.04	0.51, 1.26	0.12, 0.67

Values in blue refer to quartiles significantly ($P < 0.05$) associated with the prevalence of lumbar spine pain.

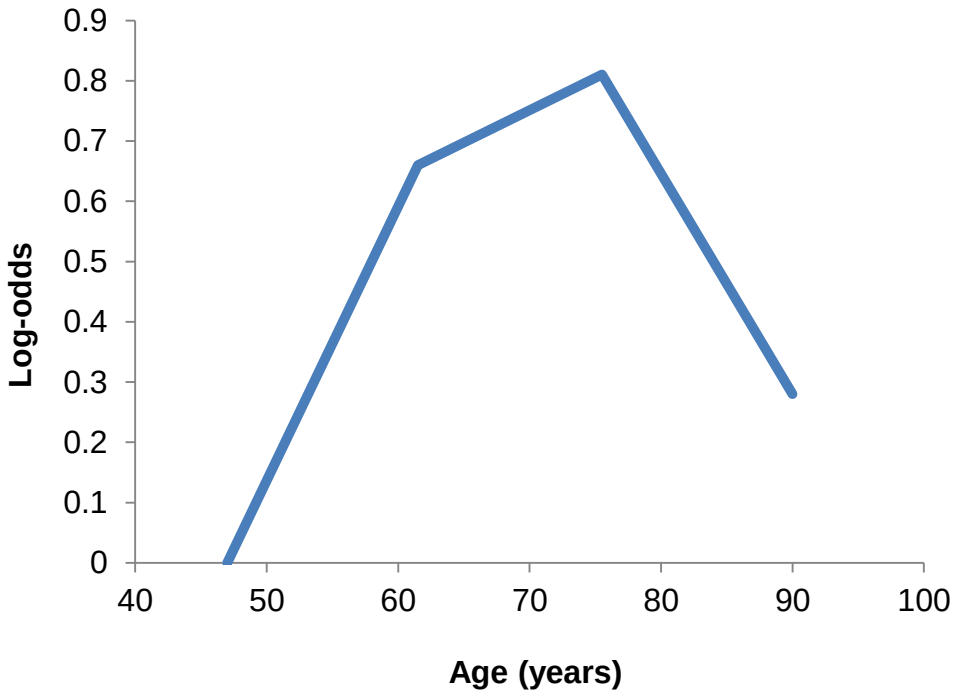


Figure 25: A Plot of Estimated Logistic Regression Coefficients for the Quartile Design Variables versus Appropriate Quartile Midpoints of Age in Relation to Lumbar Spine Pain

6.1.6.1.2 Body Mass Index

The mean BMI in GB Olympians reporting a recent history of lumbar spine pain was slightly higher (*M* = 25.32 ± 3.88 kg/m^2) than those with no lumbar spine pain (*M* = 24.58 ± 3.72 kg/m^2). Of those GB Olympians who reported a history of recent lumbar spine pain, the mean BMI was within the limits of the World Health Organisation (2004) overweight BMI category (≥ 25, < 30 kg/m^2). The mean BMI of those with no recent history of lumbar spine pain was within the limits of the normal BMI category (< 25 kg/m^2). The crude odds ratio of GB Olympians reporting that they had experienced recent lumbar spine pain was detected to be significantly associated with a one-unit increase in body mass index (kg/m^2) [OR 1.05; 95% CI, 1.00-1.10] (see Table 58). However, there was no significant association detected between BMI and lumbar spine pain following the adjustment for the remaining five covariates in the multivariable regression model [aOR 1.03; 95% CI, 0.97-1.08].

Table 58: Prevalence of Lumbar Spine Pain in Relation to Constitutional Factors (Continuous Independent Variables)

	Prevalence of Hip Pain (Mean ± SD)		Odds ratio (95% confidence interval)	
	Yes	No	Crude	Adjusted
BMI: (kg/m^2)	25.32 ± 3.88	24.58 ± 3.72	1.05 (1.00, 1.10)	1.03 (0.97, 1.08)

Values in blue refer to risk factors significantly (*P* < 0.05) associated with the prevalence of lumbar spine pain.

The results of the quartile design variable analysis of the scale of BMI (see Table 59) are plotted in Figure 26. This plot illustrates a linear trend with an increase in the log-odds for lumbar spine pain from approximately 21 kg/m^2 until it peaks at 41 kg/m^2. The log-odds for lumbar spine pain are shown to be significant after approximately 26 kg/m^2. There was a significant association detected when choosing to categorize BMI into: under / normal weight (< 25.00 kg/m^2), overweight ($\geq$ 25.00 < 30.00 kg/m^2), and obese ($\geq$ 30.00 kg/m^2). There was a significant association detected between lumbar spine pain and a BMI category of overweight [OR 1.61; 95% CI, 1.09-2.38; aOR 1.60; 95% CI, 1.03-2.49]. The BMI category of obese was, however, not detected to be significantly associated with lumbar spine pain [OR 1.31; 95% CI, 0.71-2.42; aOR 0.86; 95% CI, 0.43-1.72].

Table 59: Results of the Quartile Design Variable Analysis of the Scale of Body Mass Index

Quartile	1	2	3	4
Range	$x \leq 24.21$	$24.22 \leq x \leq 30.79$	$30.80 \leq x \leq 37.36$	$37.37 \leq x \leq 43.94$
Midpoint	20.92	27.51	34.08	40.66
Coeff.	0.0	1.22	1.45	1.81
95% CI		0.84, 1.76	0.68, 3.11	0.40, 8.29

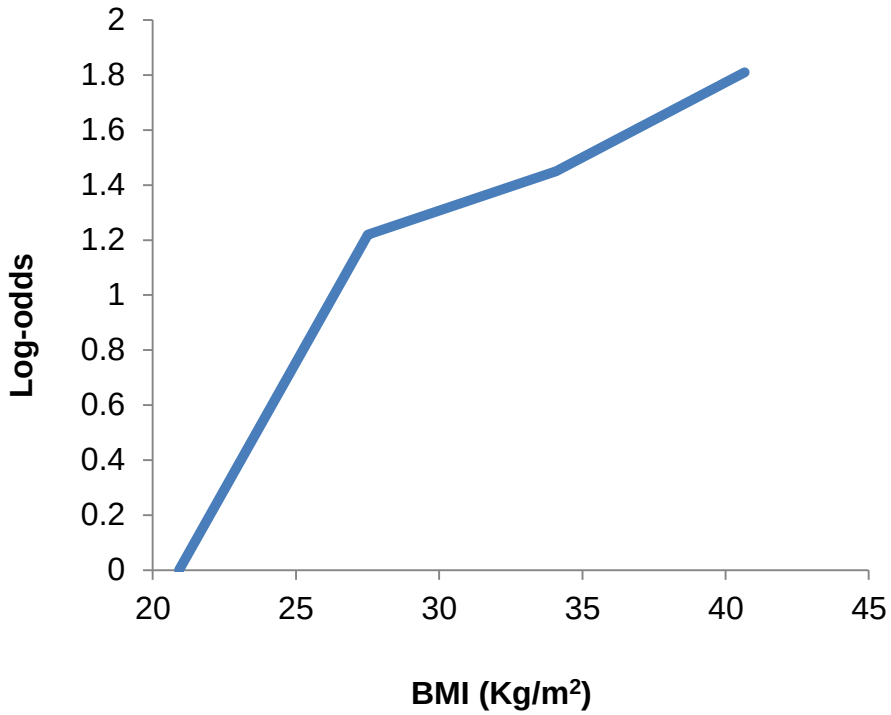


Figure 26: Plot of Estimated Logistic Regression Coefficients for the Quartile Design Variables versus Appropriate Quartile Midpoints of Body Mass Index in Relation to Lumbar Spine Pain

6.1.6.1.3 Gender

The prevalence of lumbar spine pain was similar between the sexes, with 31% (105/340) of males and 33% (74/224) of females complaining of recent lumbar spine pain (see Table 60). Gender was not detected to be significantly associated with lumbar spine pain (OR 1.10; 95% CI, 0.77-1.58), and this was confirmed following the adjustment for the remaining five covariates in the multivariable regression model [aOR 0.64; 95% CI, 0.41-1.01].

Table 60: Prevalence of Lumbar Spine Pain in Relation to Constitutional Factors (Categorical Independent Variable)

Biomechanical Factors	Prevalence rate (%)		Odds ratio (95% confidence interval)	
			Crude	Adjusted
Gender:				
Male	105/340	(31%)	**1**	**1**
Female	74/224	(33%)	1.10 (0.77, 1.58)	0.64 (0.41, 1.01)

6.1.6.2 Biomechanical Factors

6.1.6.2.1 Lumbar Spine Injury

The prevalence of lumbar spine pain was 27% (123/449) in GB Olympians with no prior history of a significant lumbar spine injury, compared to 51% (49/97) in those with a previous history of a significant lumbar spine injury (see Table 61). A previous history of a significant lumbar spine injury was detected to be significantly associated with lumbar spine pain [OR 2.71; 95% CI, 1.73-4.24]. This was confirmed after adjustment for the remaining covariates in the multivariable regression model [aOR 2.61; 95% CI, 1.62-4.22].

Table 61: Prevalence of Lumbar Spine Pain in Relation to Biomechanical Factors

Biomechanical factors	Prevalence rate (%)		Odds ratio (95% confidence interval)	
			Crude	Adjusted
Lumbar Spine injury:				
No	123/449	(27%)	**1**	**1**
Yes	49/97	(51%)	2.71 (1.73, 4.24)	2.61 (1.62, 4.22)

Values in blue refer to risk factors significantly associated with the prevalence of lumbar spine pain.

6.1.6.3 Other Factors

6.1.6.3.1 Finger Nodes

The prevalence of lumbar spine pain was 31% (157/515) in GB Olympians with fewer than one node per hand, compared to 49% (18/37) in those with one or more finger nodes per hand (see Table 62). There was a significant association detected between finger nodes and lumbar spine pain (OR 2.16; 95% CI, 1.10-4.23). However, there was no significant association detected between finger nodes and lumbar spine pain following adjustment for the remaining covariates in the multivariable regression model (aOR 2.09; 95% CI, 0.99-4.41). This covariate did however remain important, and this is illustrated by the significance value of $P = 0.053$.

Table 62: Prevalence of Lumbar Spine Pain in Relation to Finger Nodes

	Prevalence rate (%)		Odds ratio (95% confidence interval)	
			Crude	Adjusted
Finger Nodes:				
No	157/515	(31%)	**1**	**1**
Yes	18/37	(49%)	2.16 (1.10, 4.23)	2.09 (0.99, 4.41)

Values in blue refer to risk factors significantly associated with the prevalence of lumbar spine pain

6.1.6.3.2 Physical Well-Being

The mean SF-12 psychological summary score was similar in those with a recent history of lumbar spine pain (53.37 $\pm$ 8.06), compared to those without (54.02 $\pm$ 7.44). However, the mean SF-12 physical summary score was smaller in those with a recent history of lumbar spine pain (47.23 $\pm$ 10.29), compared to those without (51.50 $\pm$ 9.29). There was no relationship detected between the psychological component SF-12 summary score and lumbar spine pain [OR 0.99; 95% CI, 0.97-1.01] (see Table 63), and this covariate was omitted from the final analysis. However, as the physical component SF-12 summary score increased, the odds of GB Olympians reporting that they had experienced recent lumbar spine pain was found to be significantly lower [OR 0.96; 95% CI, 0.94-0.98]. This association was confirmed after adjustment for the remaining covariates in the multivariable regression model [aOR 0.94; 95% CI, 0.92-0.96].

Table 63: Quality of Life and the Prevalence of Lumbar Spine Pain

QOL	Prevalence of lumbar spine pain (Mean + SD)		Odds ratio (95% confidence interval)	
	Yes	No	Crude	Adjusted
SF12:				
Psychological	53.37 ± 8.06	54.02 ± 7.44	0.99 (0.97, 1.01)	N/a
Physical	47.23 ± 10.29	51.50 ± 9.29	0.96 (0.94, 0.98)	0.94 (0.92, 09.96)

Values in blue refer to risk factors significantly associated with the prevalence of lumbar spine pain.

6.2 Self-Reported Physician-Diagnosed Knee Osteoarthritis

The purpose of the following data analysis was to identify the individual risk factors associated with self-reported, physician-diagnosed OA in Great Britain's Olympians aged 40 years and older. Three separate models of binary logistic regression were constructed to examine covariates associated with OA at the knee, hip and the lumbar spine. The strategy for building each of the three multivariable regression models began by selecting relevant covariates of known clinical importance. Age, body mass index and gender were considered to be clinically relevant based on previous studies (Silverwood et al. 2015; Blagojevic et al. 2010; Lachance et al. 2002; Miranda et al. 2002), and were included irrespective of their statistical significance. Further covariates were selected based on their significance in relation to the dependent variable of interest. The steps taken to select these covariates are explained below.

6.2.1 Self-Reported Physician-Diagnosed Knee Osteoarthritis

6.2.1.1 Purposeful Selection of Covariates

A series of chi-square tests of independence were performed to determine whether or not there was an association between 11 covariates and knee OA (see Table 64). The covariates - age, body mass index, knee injury, early-life (20-29 years) generalised joint hypermobility (GJH), comorbidities, finger nodes, and impact sport - were detected to be significantly associated with knee pain at the 25% level (i.e. $P < 0.25$). Five covariates - gender, early-life (20-29 years) knee mal-alignment, weight-bearing loading sports, and index ring finger ratio - were not significantly associated with knee pain ($P > 0.25$).

6.2.1.2 Fitting the Multivariable Regression Model

All covariates identified for inclusion in the univariable regression model, along with those of clinical relevance, were fitted into the multivariable regression model (see Table 65). The importance of the covariates added to the multivariable regression model was assessed using the *p*-value of the Wald statistic and a traditional significance level of $P < 0.05$. The following covariates: early-life (20-29 years) knee mal-alignment, impact sport, and index ring finger ratio did not contribute significantly to the model and were eliminated. When a new, smaller multivariable regression model was adopted, the covariates – gender, comorbidities, finger nodes, and impact sport - were also eliminated.

6.2.1.3 Refitting the Multivariable Regression Model

Covariates excluded from the multivariable regression model were added, one at a time, to a revised model, along with each of the covariates which had been excluded from the univariable model. The values of the estimated coefficients for previous knee injury, GJH (20-29 years), comorbidities, finger nodes and impact sport were compared to their respective values from the larger earlier model. Neither of the coefficients changed markedly in magnitude and none were deemed important for providing a necessary adjustment for the variables that remained in the model. This process helped to construct the preliminary results model containing all of the essential covariates (see Table 66).

6.2.1.4 Checking for Interactions in the Main Effects Model

A list of possible interactions was constructed. From this list, interactions among the variables in the model were assessed (Appendix T: Table 92). None of the interactions was included in the multivariable regression model; they were not statistically significant ($P < 0.05$).

6.2.1.5 Checking the Fit of the Model

The logistic regression model using five predictors (age, body mass index, gender, previous knee injury and GJH) was able to correctly classify 88% of cases. The chi-square value for the Hosmer and Lemeshow (Test 6.609, $P = 0.579$) indicated support for the fit of the final multivariable regression model ($P > 0.05$).

Table 64: Results of Fitting the Univariable Logistic Regression Knee Osteoarthritis Model, *n* = 597

	Coeff.	Std.Err.	OR	95% CI	X^2	*p*
AGE	0.05	0.01	1.05	1.03, 1.07	*t (595) = -5.38***	0.001
BMI (without outlier)	0.07	0.03	1.07	1.01, 1.14	*t (589) = -2.48***	0.05
GENDER	-0.19	0.24	0.83	0.51, 1.33	0.63*	0.43
PRIOR KNEE INJURY	1.22	0.28	3.40	1.98, 5.84	21.54*	0.001
KNEE MALALIGNMENT (varus)	-0.06	0.46	0.94	0.39, 2.31	0.11**	0.74
SPORT: W.B. LOADING	0.18	0.24	1.20	0.74, 1.93	0.53*	0.47
HYPERMOBILITY	0.72	0.33	2.05	1.08, 3.89	4.95*	0.03
COMORBIDITIES (≥ 2)	1.23	0.30	3.42	1.89, 6.19	22.18**	0.001
2D: 4D (Index < Ring)	0.05	0.28	1.05	0.61, 1.81	0.03**	0.86
FINGER NODES	0.67	0.40	1.96	0.89, 4.29	2.90**	0.09
SPORT: IMPACT	0.44	0.28	1.56	0.91, 2.69	2.60*	0.11

Pearson chi-square test used for categorical variables with two levels. **Pearson linear-by-linear reported on for ordinal categorical data. ***Independent-samples t-test used for continuous data. Values in blue refer to covariates significantly associated with the prevalence of knee OA at $P < 0.25$.

Table 65: Results of Fitting the Multivariable Regression Knee Osteoarthritis Model with all Covariates Significant at the 0.25 Level in the Univariable Analysis

	Coeff.	Std.Err.	*P*	aOR	95% CI
AGE	0.05	0.01	0.001	1.05	1.02, 1.08
BMI (without outlier)	0.08	0.04	0.04	1.08	1.01, 1.16
GENDER	0.43	0.35	0.22	1.54	0.78, 3.07
PRIOR KNEE INJURY	1.59	0.32	0.001	4.92	2.62, 9.24
HYPERMOBILITY (20-29 years)	0.91	0.39	0.02	2.49	1.16, 5.34
COMORBIDITIES (≥ 2)	0.71	0.40	0.08	2.03	0.93, 4.44
FINGER NODES	0.11	0.52	0.84	1.11	0.40, 3.07
SPORT: IMPACT	0.26	0.36	0.46	1.30	0.65, 2.62

Values in blue refer to risk factors significantly ($P < 0.05$) associated with the prevalence of knee osteoarthritis.

Table 66: Results of Refitting the Multivariable Regression Knee Osteoarthritis Model with all Covariates Significant at the 0.05 Level

	Coeff.	Std.Err.	*P*	aOR	95% CI
AGE	0.06	0.01	0.001	1.06	1.03, 1.09
BMI (without outlier)	0.10	0.04	0.01	1.10	1.03, 1.18
GENDER	0.42	0.32	0.19	1.52	0.81, 2.84
PRIOR KNEE INJURY	1.59	0.31	0.001	4.89	2.64, 9.06
HYPERMOBILITY (20-29 years)	0.82	0.38	0.03	2.26	1.08, 4.74

Values in blue refer to risk factors significantly ($P < 0.05$) associated with the prevalence of knee osteoarthritis.

6.2.1.6 Checking for Multicollinearity

The assumption of multicollinearity was not violated because the correlations between the covariates were not greater than *r* = .7 (Appendix U: Table 101). The tolerance value for each independent variable was not less than 0.10, and the variance inflation factor was not above 10 (Appendix U: Table 102) (Pallant 2007).

6.2.2 Risk Factors Associated with Self-Reported Physician-Diagnosed Knee Osteoarthritis

The final multivariable regression model investigated whether or not there was a significant association between self-reported, physician-diagnosed knee OA and the following five covariates: age, body mass index, gender, previous knee injury and GJH in early-life (20-29 years). The results for each covariate included in the multivariable regression model are discussed below.

6.2.2.1 Constitutional Factors

6.2.2.1.1 Age

The mean age of GB Olympians with knee OA (*M* = 70.32 $\pm$ 11.86 years) is greater than that of those reporting no history of knee OA (*M* = 62.18 $\pm$ 13.07 years). The crude odds ratio indicated a significant association between knee OA and a one-unit increase in age [OR 1.05; 95% CI, 1.03-1.07] (see Table 67), and this was confirmed following the adjustment for the remaining four covariates [aOR 1.06; 95% CI, 1.03-1.09]. The results of the quartile design variable analysis of the scale of

age (see Table 68) are plotted in Figure 27. This plot illustrates a quadratic trend with a linear increase in the log-odds for knee OA from approximately 47 years of age until it peaks at 75 years. The trend then changes direction and declines**,** whilst remaining significant from approximately 57 years. There was a significant association detected when choosing to categorise age into: 40-59 years and older than 59 years [OR 3.23; 95% CI, 1.87-5.60; aOR 4.05; 95% CI, 2.08-7.88].

Table 67: Prevalence of Knee Osteoarthritis in Relation to Constitutional Factors (Continuous Independent Variables)

	Prevalence of Knee OA (Mean ± SD)		Odds ratio (95% confidence interval)	
	Yes	No	Crude	Adjusted
Age: (Years)	70.32 ± 11.86	62.18 ± 13.07	1.05 (1.03, 1.07)	1.06 (1.03, 1.09)
BMI: (kg/m^2)	25.70 ± 4.77	24.62 ± 3.46	1.07 (1.01, 1.14)	1.10 (1.03, 1.18)

Values in blue refer to risk factors significantly ($P < 0.05$) associated with the prevalence of knee OA.

Table 68: Results of the Quartile Design Variable Analysis of the Scale of Age

Quartile	1	2	3	4
Range	$x \leq 54$	$55 \leq x \leq 68$	$69 \leq x \leq 82$	$83 \leq x \leq 97$
Midpoint	47	61.5	75.5	90
Coeff.	0.0	1.50	4.69	4.43
95% CI		0.70, 3.17	2.38, 9.26	1.81, 10.84

Values in blue refer to quartiles significantly ($P < 0.05$) associated with the prevalence of knee osteoarthritis.

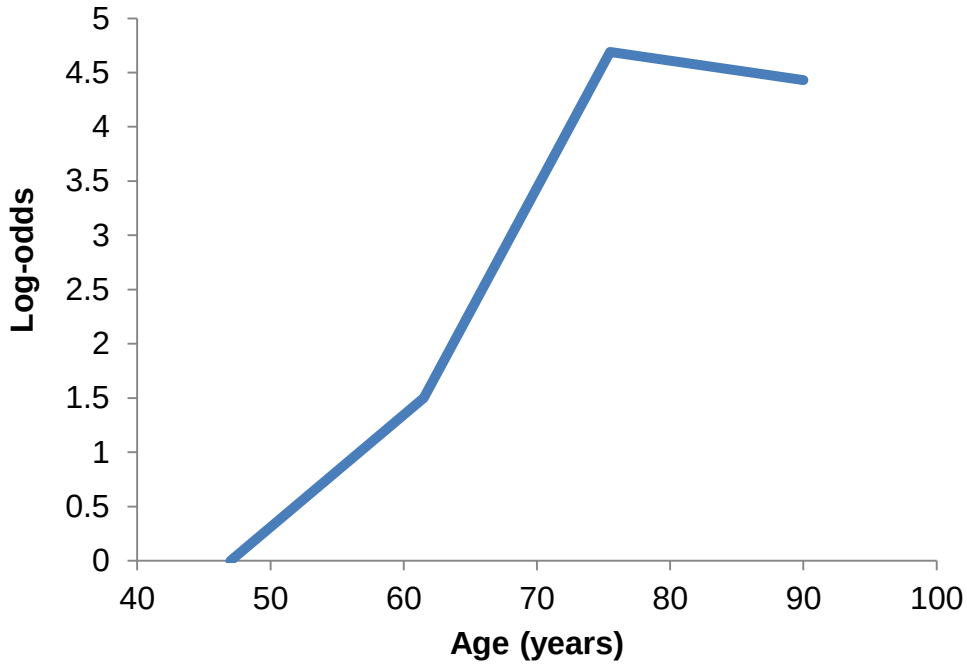


Figure 27: Plot of Estimated Logistic Regression Coefficients for the Quartile Design Variables versus Appropriate Quartile Midpoints of Age in Relation to Knee Osteoarthritis

6.2.2.1.2 Body Mass Index

The mean BMI in GB Olympians with knee OA was slightly higher (*M* = 25.70 $\pm$ 4.77 kg/m^2) than those without knee pain (*M* = 24.62 $\pm$ 3.46 kg/m^2). Of those GB Olympians reporting a history of knee OA, the mean BMI was within the limits of the World Health Organisation (2004) overweight BMI category ($\geq$ 25, < 30 kg/m^2). The mean BMI in GB Olympians with no history of knee OA is within the limits of the normal BMI category (< 25 kg/m^2). The crude odds ratio of GB Olympians reporting knee OA was significantly associated with a one-unit increase in body mass index (kg/m^2) [OR 1.07; 95% CI, 1.01-1.14] (see Table

67). This was confirmed after adjustment for the remaining covariates in the multivariable regression model [aOR 1.10; 95% CI, 1.03-1.18].

The results of the quartile design variable analysis of the scale of BMI (see Table 69) are plotted in Figure 28. The log-odds for knee OA increases significantly after 27.5 kg/m^2, and this is followed by plateau at approximately 34 kg/m^2. This plateau is possibly due to a limited number of outcome cases in those with a BMI of $\geq$ 33 kg/m^2. There was no significant association detected between knee OA and a BMI category of overweight ($\geq$ 25.00 < 30.00 kg/m^2) [OR 0.94; 95% CI, 0.55-1.62; aOR 0.92; 95% CI, 0.46-1.81]. However, there was a significant association between knee OA and the BMI category of obese ($\geq$ 30.00 kg/m^2) [OR 2.69; 95% CI, 1.37-5.27; aOR 3.41; 95% CI, 1.54-7.52].

Table 69: Results of the Quartile Design Variable Analysis of the Scale of Body Mass Index

Quartile	1	2	3	4
Range	$x \leq$ 24.21	24.22 $\leq x \leq$ 30.79	30.80 $\leq x \leq$ 37.36	37.37 $\leq x \leq$ 43.94
Midpoint	20.92	27.51	34.08	40.66
Coeff.	0.0	1.03	3.49	3.49
95% CI		0.62, 1.70	1.56, 7.79	0.62, 19.72

Values in blue refer to quartiles significantly (P < 0.05) associated with the prevalence of knee osteoarthritis.

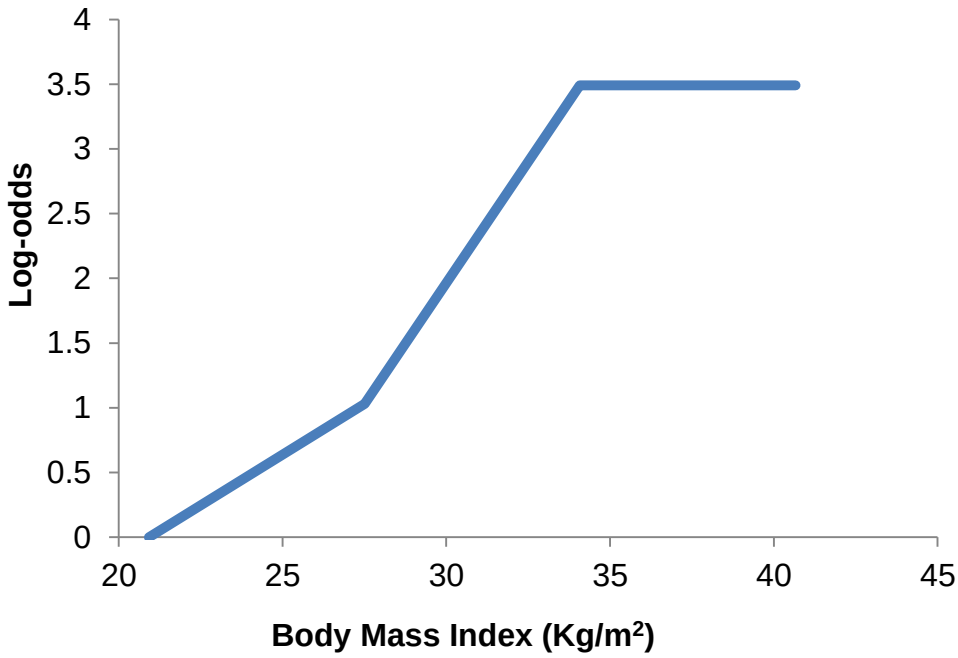


Figure 28: Plot of Estimated Logistic Regression Coefficients for the Quartile Design Variables versus Appropriate Quartile Midpoints of Body Mass Index in Relation to Knee Osteoarthritis

6.2.2.1.3 Gender

The prevalence of knee OA was similar between the sexes, with 15% (54/356) of males and 13% (31/241) of females reporting that they had previously been diagnosed with knee OA by a physician. Gender was not detected to be significantly associated with knee OA (OR 0.83; 95% CI, 0.51-1.33), and this was confirmed after adjustment for the remaining four covariates in the multivariable regression model [aOR 1.52; 95% CI, 0.81-2.84] (see Table 70).

Table 70: Prevalence of Knee Osteoarthritis in Relation to Constitutional Factors (Categorical Independent Variables)

Biomechanical Factors	Prevalence rate (%)		Odds ratio (95% confidence interval)	
			Crude	Adjusted
Gender:				
Male	54/356	(15%)	**1**	**1**
Female	31/241	(13%)	0.83 (0.51, 1.33)	1.52 (0.81, 2.84)

6.2.2.2 Biomechanical Factors

6.2.2.2.1 Knee Injury

The prevalence of knee OA was 11% (53/483) in GB Olympians with no prior history of a significant knee injury, compared to 30% (26/88) in those with a previous history of a significant knee injury (see Table 71). The crude odds ratio detected a significant association between a previous significant knee injury and knee OA [OR 3.40; 95% CI, 1.98-5.84]. This was confirmed after adjustment for the remaining four covariates in the multivariable regression model [aOR 4.89; 95% CI, 2.64-9.06].

Table 71: Prevalence of Knee Osteoarthritis in Relation to Biomechanical Factors (Categorical Independent Variables)

Biomechanical Factors	Prevalence rate (%)	Odds ratio (95% confidence interval)	
		Crude	Adjusted
Previous Knee Injury:			
No	53/483 (11%)	**1**	**1**
Yes	26/88 (30%)	3.40 (1.98, 5.84)	4.89 (2.64, 9.06)
Hypermobility in 20s			
No (< 4/9 Beighton)	52/435 (12%)	**1**	1
Yes (≥ 4/9Beighton)	15/69 (22%)	2.05 (1.08, 3.89)	2.26 (1.08, 4.74)

Values in blue refer to risk factors significantly ($P < 0.05$) associated with the prevalence of knee OA.

6.2.2.2.2 Generalised Joint Hypermobility

The prevalence of knee OA was 12% (52/435) in GB Olympians in the non-hypermobile group (Beighton < 4/9), and 22% (15/69) among GB Olympians with GJH (Beighton ≥ 4/9) in early-life (20-29 years) (see Table 71). The crude odds ratio detected that the risk of developing knee OA was significantly associated with GJH in early-life [OR 2.05; 95% CI, 1.08-3.89]. This association was confirmed following the adjustment for the remaining four covariates in the multivariable regression model [aOR 2.26; 95% CI, 1.08-4.74]. Furthermore, female athletes with generalised joint hypermobility in early-life (20-29 years) were more vulnerable [OR, 2.53; 95% CI, 1.06-6.00] to knee OA than

their male counterparts [OR 1.69; 95% CI, 0.60-4.80].

6.2.3 Analysis of Self-Reported Physician-Diagnosed Hip Osteoarthritis

6.2.3.1 Purposeful Selection of Covariates

A series of chi-square tests of independence were performed to determine whether there was an association between 11 covariates and hip OA (see Table 72). The covariates – age, gender, prior hip injury, weight-bearing loading sports, and comorbidities - were detected to be significantly associated with knee pain at the 25% level (i.e. $P < 0.25$). Six covariates - BMI, early-life (20-29 years) knee mal-alignment, GJH in early life (20-29 years), index ring finger ratio, finger nodes and impact sport - were not detected to be significantly associated with knee pain ($P > 0.25$).

6.2.3.2 Fitting the Multivariable Regression Model

All covariates identified for inclusion in the univariable regression model, along with those of clinical relevance, were fitted into the multivariable regression model (see Table 73). The importance of the covariates added to the multivariable regression model was assessed using the *p*-value of the Wald statistic and a traditional significance level of $P < 0.05$. Two covariates (weight-bearing loading sports and comorbidities) did not contribute to the model significantly and were eliminated. A new, smaller model was fitted (see Table 74).

6.2.3.3 Refitting the Multivariable Regression Model

Covariates which had been excluded from the multivariable regression model were added, one at a time, to a revised model, along with each of the covariates that had been excluded from the univariable model. The values of the estimated coefficients for age, BMI, gender, and previous hip injury were compared to their respective values from the larger earlier model. Neither of the coefficients changed markedly in magnitude, and none of the excluded covariates were considered important in terms of providing a necessary adjustment for the variables that remained in the model. This process helped to construct the preliminary results model which contained all the essential covariates (see Table 74).

6.2.3.4 Checking for Interactions in the Main Effects Model

A list of possible interactions was constructed. From this list, interactions among the variables in the model were assessed (Appendix T: Table 93). None of the interactions was included in the multivariable regression model; they were not statistically significant ($P < 0.05$).

6.2.3.5 Checking the Fit of the Model

The logistic regression model using four predictors (age, body mass index, gender, previous hip injury) was able to classify correctly 89% of cases. The chi-square value for the Hosmer and Lemeshow Test (2.259, $P = 0.972$) indicated support for the fit of the final regression model ($P > 0.05$).

Table 72: Results of Fitting the Univariable Regression Hip Osteoarthritis Model, *n* = 597

	Coeff.	Std.Err.	OR	95% CI	X^2	*P*
AGE	0.06	0.01	1.06	1.04, 1.08	*t* (594) = -5.78***	0.001
BMI (without outlier)	0.01	0.04	1.01	0.94, 1.08	*t* (588) = *-0.18***	0.86
GENDER	-0.42	0.28	0.66	0.38, 1.14	2.29*	0.13
PRIOR HIP INJURY	2.18	0.49	8.86	3.38, 23.23	27.41*	0.001
KNEE ALIGNMENT (varus)	-0.23	0.54	0.80	0.28, 2.31	0.15**	0.70
SPORT: W.B. LOADING	0.51	0.29	1.66	0.95, 2.91	3.21*	0.07
HYPERMOBILITY	-0.24	0.45	0.78	0.32, 1.91	0.29*	0.59
COMORBIDITIES (≥ 2)	1.05	0.33	2.85	1.49, 5.46	11.16**	0.001
2D: 4D (Index < Ring)	-0.12	0.31	0.89	0.49, 1.62	0.17**	0.68
FINGER NODES	-0.09	0.55	0.91	0.31, 2.66	0.03**	0.87
SPORT: IMPACT	0.10	0.32	1.11	0.58, 2.12	0.10*	0.75

Pearson chi-square test used for categorical variables with two levels. **Pearson linear-by-linear reported on for ordinal categorical data. ***Independent-samples t-test reported on for continuous data. Values in blue refer to covariates significantly associated with the prevalence of knee OA at $P < 0.25$.

Table 73: Results of Fitting the Multivariable Regression Hip Osteoarthritis Model with all Covariates Significant at the 0.25 Level in the Univariable Analysis

	Coeff.	Std.Err.	*P*	aOR	95% CI
AGE	0.05	0.01	0.001	1.06	1.03, 1.08
BMI (without outlier)	-0.01	0.04	0.76	0.99	0.91, 1.07
GENDER	0.03	0.32	0.92	1.03	0.55, 1.92
PRIOR HIP INJURY	2.35	0.55	0.001	10.45	3.59, 30.47
SPORT: W.B. LOADING	0.32	0.31	0.30	1.38	0.76, 2.50
COMORBIDITIES (≥ 2)	0.58	0.39	0.14	1.78	0.83, 3.82

Values in blue refer to risk factors significantly ($P < 0.05$) associated with the prevalence of hip osteoarthritis.

Table 74: Results of Refitting the Multivariable Regression Hip Osteoarthritis Model with all Covariates Significant at the 0.05 Level

	Coeff.	Std.Err.	*P*	aOR	95% CI
AGE	0.06	0.01	0.001	1.06	1.04, 1.09
BMI (without outlier)	-0.002	0.04	0.96	1.00	0.92, 1.08
GENDER	-0.001	0.32	0.998	1.00	0.54, 1.85
PRIOR HIP INJURY	2.35	0.54	0.001	10.46	3.67, 29.83

Values in blue refer to risk factors significantly ($P < 0.05$) associated with the prevalence of hip osteoarthritis.

6.2.3.6 Checking for Multicollinearity

The assumption of multicollinearity was not violated because the correlations between the covariates were not greater than $r = .7$ (Appendix U: Table 103). The tolerance value for each independent variable was not less than 0.10, and the variance inflation factor was not above 10 (Appendix U: Table 104) (Pallant 2007).

6.2.4 Risk Factors Associated with Self-Reported Physician-Diagnosed Hip Osteoarthritis

The final multivariable regression model investigated whether or not there was a significant association between self-reported, physician-diagnosed hip OA and the following four covariates: age, body mass index, gender and previous hip injury. The results of the crude and adjusted odds ratios for each covariate included in the model are discussed below.

6.2.4.1 Constitutional Factors

6.2.4.1.1 Age

The mean age of GB Olympians with hip OA ($M = 71.94 \pm 11.69$ years) is greater than those reporting no history of hip OA ($M = 62.24 \pm 12.99$ years). The crude odds ratio indicated a significant association between hip OA and a one-unit increase in age [OR 1.06; 95% CI, 1.04-1.08] (see Table 75), and this was confirmed following the adjustment for the remaining four covariates [aOR 1.06; 95% CI, 1.04-1.09]. The results of the quartile design variable analysis of the scale of age (see Table 76)

are plotted in Figure 29. This plot illustrates a linear trend, with an increase in the log-odds for hip OA from approximately 47 years of age until 90 years. The trend becomes significant at approximately 52 years. There was also a significant association detected when choosing to categorise age into: 40-59 years and older than 59 years [OR 3.45; 95% CI, 1.84-6.48; aOR 3.44; 95% CI, 1.77-6.67].

Table 75: Prevalence of Hip Osteoarthritis in Relation to Constitutional Factors (Continuous Independent Variables)

	Prevalence of Hip OA (Mean ± SD)		Odds ratio (95% confidence interval)	
	Yes	No	Crude	Adjusted
Age: (Years)	71.94 ± 11.69	62.24 ± 12.99	1.06 (1.04, 1.08)	1.06 (1.04, 1.09)
BMI: (kg/m^2)	24.84 ± 3.82	24.76 ± 3.67	1.01 (0.94, 1.08)	1.00 (0.92, 1.08)

Values in blue refer to risk factors significantly ($P < 0.05$) associated with the prevalence of hip osteoarthritis.

Table 76: Results of the Quartile Design Variable Analysis of the Scale of Age

Quartile	1	2	3	4
Range	$x \leq 54$	$55 \leq x \leq 68$	$69 \leq x \leq 82$	$83 \leq x \leq 97$
Midpoint	47	61.5	75.5	90
Coeff.	0.0	2.64	4.87	8.77
95% CI		1.08, 6.43	2.07, 11.47	3.22, 23.90

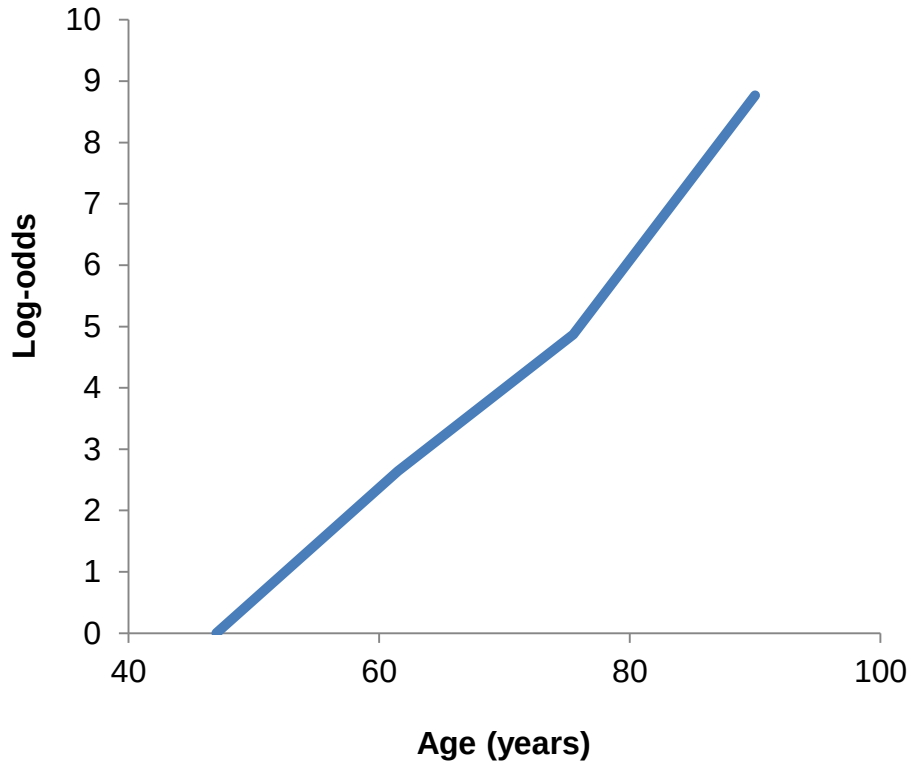


Figure 29: Plot of Estimated Logistic Regression Coefficients for the Quartile Design Variables versus Appropriate Quartile Midpoints of Age in Relation to Hip Osteoarthritis

6.2.4.1.2 Body Mass Index

The mean BMI in GB Olympians with hip OA was only marginally greater (*M* = 24.84 ± 3.82 kg/m^2) than those with no hip OA (*M* = 24.76 ± 3.67 kg/m^2), and both groups were within the limits of the World Health Organisations (2004) normal BMI category (< 25 kg/m^2). The crude odds ratio of GB Olympians reporting hip OA was not detected to be significantly associated with a one-unit increase in BMI (kg/m^2) [OR 1.01; 95% CI, 0.94-1.08] (see Table 75). This was confirmed after

adjustment for the remaining four covariates in the multivariable regression model [aOR 1.00; 95% CI, 0.92-1.08].

The results of the quartile design variable analysis of the scale of BMI (see Table 77) are plotted in Figure 30. This plot illustrates a cubic trend where the log-odds for hip OA at first goes up from 22 to 27 kg/m^2 and becomes significant at approximately 26.5 kg/m^2. The log-odds for hip OA then goes down from 26.5 kg/m^2 to 34 kg/m^2, before rising again at 35 kg/m^2. Although the log-odds failed to show a linear relationship between BMI and hip OA, there was no significant association when choosing to categorize BMI into: under / normal weight (< 25 kg/m^2); overweight ($\geq$ 25 < 30 kg/m^2) [OR 1.20; 95% CI, 0.69-2.08; aOR 1.31; 95% CI, 0.72-2.39] and obese ($\geq$ 30 kg/m^2) [OR 0.67; 95% CI, 0.23-1.96; aOR 0.66; 95% CI, 0.22-2.00].

Table 77: Results of the Quartile Design Variable Analysis of the Scale of Body Mass Index

Quartile	1	2	3	4
Range	$x \leq$ 24.21	24.22 $\leq x \leq$ 30.79	30.80 $\leq x \leq$ 37.36	37.37 $\leq x \leq$ 43.94
Midpoint	20.92	27.51	34.08	40.66
Coeff.	0.0	1.18	0.86	1.71
95% CI		0.70, 2.01	0.25, 2.98	0.19, 15.16

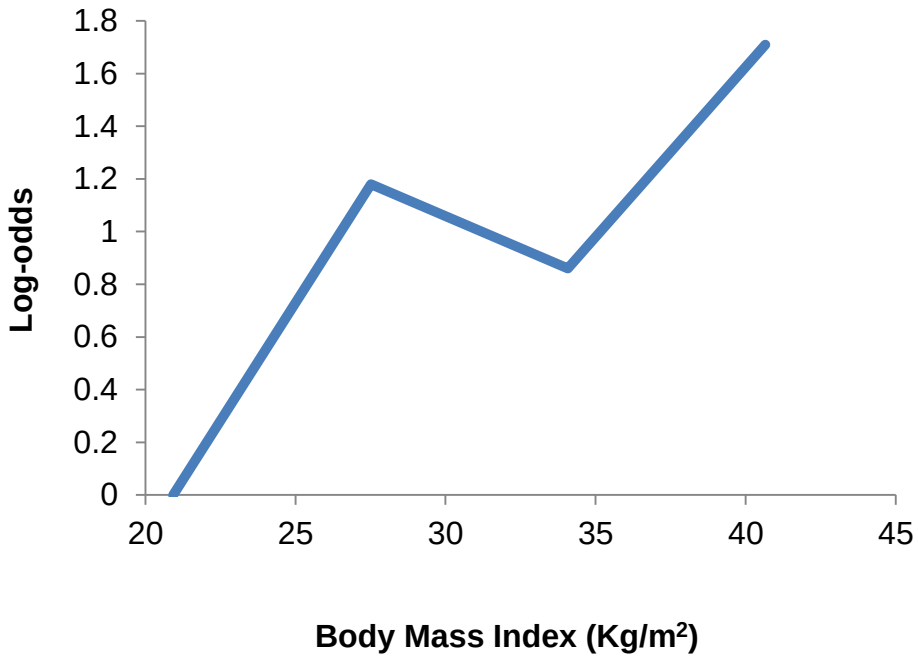


Figure 30: Plot of Estimated Logistic Regression Coefficients for the Quartile Design Variables versus Appropriate Quartile Midpoints of Body Mass Index in Relation to Hip Osteoarthritis

6.2.4.1.3 Gender

The prevalence of hip OA was 13% (45/355) in males and 9% (21/241) in female GB Olympians aged 40 years and older (see Table 78). No significant association was detected between gender and hip OA [OR 0.66; 95% CI, 0.38-1.14], and this was confirmed after adjustment for the remaining covariates in the multivariable regression model [aOR 1.00; 95% CI, 0.54-1.85].

Table 78: Prevalence of Hip Osteoarthritis in Relation to Constitutional Factors (Categorical Independent Variables)

Biomechanical Factors	Prevalence rate (%)		Odds ratio (95% confidence interval)	
			Crude	Adjusted
Gender:				
Male	45/355	(13%)	**1**	**1**
Female	21/241	9%	0.66 (0.38, 1.14)	1.00 (0.54, 1.85)

6.2.4.2 Biomechanical Factors

6.2.4.2.1 Hip Injury

Of the 18 GB Olympians with a previous history of a significant hip injury, 50% (9/18) reported hip OA (see Table 79). Among the 552 GB Olympians with no previous history of a significant hip injury, 10% (56/552) reported hip OA. GB Olympians with a previous history of a significant hip injury were approximately nine times [OR 8.86; 95% CI, 3.38-23.23] more likely to report hip OA. This was confirmed after adjustment for the remaining covariates in the multivariable regression model [aOR 10.46; 95% CI, 3.67-29.83].

Table 79: Prevalence of Hip Osteoarthritis in Relation to Biomechanical Factors (Categorical Independent Variables)

Biomechanical Factors	Prevalence rate (%)	Odds ratio (95% confidence interval)	
		Crude	Adjusted
Previous Hip Injury:			
No	56/552 (10%)	**1**	**1**
Yes	9/18 (50%)	8.86 (3.38, 23.23)	10.46 (3.67, 29.83)

Values in blue refer to risk factors significantly ($P < 0.05$) associated with the prevalence of hip OA.

6.2.5 Analysis of Self-Reported Physician-Diagnosed Lumbar Spine Osteoarthritis

6.2.5.1 Purposeful Selection of Covariates

A series of chi-square tests of independence were performed to determine whether there was an association between 11 covariates and lumbar spine OA (see Table 80). The covariates – age, gender, weight-bearing loading sport, comorbidities, finger nodes and impact sport - were detected to be significantly associated with lumbar spine OA at the 25% level (i.e. $P < 0.25$). Five covariates - BMI, prior lumbar spine injury, early-life (20-29 years) knee mal-alignment, GJH in early-life (20-29 years), and the index ring finger ratio - were not detected to be significantly associated with lumbar spine OA ($P > 0.25$).

6.2.5.2 Fitting the Multivariable Regression Model

All covariates identified for inclusion in the univariable regression model, along with those of clinical relevance, were fitted into the multivariable regression model (see Table 81). The importance of the covariates added to the multivariable regression model was assessed using the *p*-value of the Wald statistic and a traditional significance level of $P < 0.05$. Four covariates (weight-bearing loading sports, comorbidities, finger nodes and impact sport) did not contribute to the model significantly and were eliminated. A new, smaller model was fitted (see Table 82).

6.2.5.3 Refitting the Multivariable Regression Model

Covariates which had been excluded from the multivariable regression model were added, one at a time, to a revised model, along with each of the covariates that had been excluded from the univariable model. The values of the estimated coefficients for age, BMI, and gender were compared to their respective values from the larger earlier model. Neither of the coefficients changed markedly in magnitude, and none of the excluded covariates were considered important in terms of providing a necessary adjustment for the variables that remained in the model. This process helped to construct the preliminary results model which contained all the essential covariates (see Table 82).

Table 80: Results of Fitting the Univariable Regression Lumbar Spine Osteoarthritis Model, *n* = 597

	Coeff.	Std.Err.	OR	95% CI	X^2	*P*
AGE	0.03	0.01	1.04	1.01, 1.06	*t* (595) = -2.39***	0.02
BMI (without outlier)	0.004	0.05	1.00	0.91, 1.11	*t* (589) = *-0.08***	0.94
GENDER	1.30	0.41	3.68	1.66, 8.18	11.52	0.001
PRIOR LUMBAR SPINE INJURY	-0.27	0.55	0.77	0.26, 2.25	0.24*	0.63
KNEE ALIGNMENT (varus)	-0.88	1.03	0.42	0.06, 3.14	0.200**	0.66
SPORT: W.B. LOADING	-0.48	0.38	0.62	0.30, 1.29	1.65*	0.20
HYPERMOBILITY	0.41	0.57	1.51	0.49, 4.64	0.53*	0.47
COMORBIDITIES (≥ 2)	0.57	0.45	1.77	0.74, 4.24	1.73**	0.19
2D: 4D (Index < Ring)	-0.55	0.41	0.58	0.26, 1.29	1.79**	1.81
FINGER NODES	1.43	0.49	4.16	1.58, 10.91	9.72**	0.002
SPORT: IMPACT	-1.19	0.74	0.30	0.07, 1.29	2.91*	0.09

Pearson chi-square test used for categorical variables with two levels. **Pearson linear-by-linear reported on for ordinal categorical data. ***Independent-samples t-test reported on for continuous data. Values in blue refer to covariates significantly associated with the prevalence of knee OA at $P < 0.25$.

Table 81: Results of Fitting the Multivariable Regression Lumbar Spine Osteoarthritis Model with all Covariates Significant at the 0.25 Level in the Univariable Analysis

	Coeff.	Std.Err.	*P*	OR	95% CI
AGE	0.05	0.02	0.02	1.05	1.01, 1.08
BMI (without outlier)	0.01	0.05	0.84	1.01	0.91, 1.12
GENDER	1.22	0.47	0.01	3.40	1.36, 8.47
SPORT: W.B. LOADING	-0.50	0.43	0.25	0.61	0.26, 1.41
COMORBIDITIES (≥ 2)	0.002	0.56	1.00	1.00	0.37, 2.99
FINGER NODES	0.93	0.56	0.09	2.54	0.86, 7.54
SPORT: IMPACT	-0.65	0.80	0.41	0.52	0.11, 2.48

Values in blue refer to risk factors significantly ($P < 0.05$) associated with the prevalence of hip osteoarthritis.

Table 82: Results of Refitting the Multivariable Regression Lumbar Spine Osteoarthritis Model with all Covariates Significant at the 0.05 Level

	Coeff.	Std.Err.	*P*	OR	95% CI
AGE	0.05	0.02	0.001	1.05	1.02, 1.09
BMI (without outlier)	0.03	0.05	0.57	1.03	0.93, 1.13
GENDER	1.66	0.44	0.001	5.28	2.22, 12.55

Values in blue refer to risk factors significantly ($P < 0.05$) associated with the prevalence of hip osteoarthritis.

6.2.5.4 Checking for Interactions in the Main Effects Model

A list of possible interactions was constructed. From this list, interactions among the variables in the model were assessed (Appendix T: Table 94). None of the interactions was included in the multivariable regression model; they were not statistically significant ($P < 0.05$).

6.2.5.5 Checking the Fit of the Model

The logistic regression model using three predictors (age, body mass index, and gender) was able to classify correctly 95% of cases. The chi-square value for the Hosmer and Lemeshow Test (4.964, $P = 0.761$) indicated support for the fit of the final regression model ($P > 0.05$).

6.2.5.6 Checking for Multicollinearity

The assumption of multicollinearity was not violated because the correlations between the covariates were not greater than $r = .7$ (Appendix U: Table 105). The tolerance value for each independent variable was not less than 0.10, and the variance inflation factor was not above 10 (Appendix U: Table 106) (Pallant 2007).

6.2.6 Risk Factors Associated with Self-Reported Physician-Diagnosed Lumbar Spine Osteoarthritis

6.2.6.1 Constitutional Factors

6.2.6.1.1 Age

The mean age of GB Olympians with self-reported, physician-diagnosed lumbar spine OA (*M* = 68.93 ± 11.13 years) was greater than those reporting no history of lumbar spine OA (*M* = 63.04 ± 13.25 years). The crude odds ratio of GB Olympians reporting lumbar spine OA was significantly associated with a one-unit increase in age [OR 1.04; 95% CI, 1.01-1.06] (see Table 83). This was confirmed after adjustment for the remaining covariates in the multivariable regression model [aOR 1.05; 95% CI, 1.02-1.09].

Table 83: Prevalence of Lumbar Spine Osteoarthritis in Relation to Constitutional Factors (Continuous Independent Variable)

	Prevalence of Hip OA (Mean ± SD)		Odds ratio (95% confidence interval)	
	Yes	No	Crude	Adjusted
Age: (Years)	68.93 ± 11.13	63.04 ± 13.25	1.04 (1.01, 1.06)	1.05 (1.02, 1.09)
BMI: (kg/m^2)	24.83 ± 3.49	24.77 ± 3.70	1.00 (0.91, 1.11)	1.03 (0.93, 1.13)

Values in blue refer to risk factors significantly (*P* < 0.05) associated with the prevalence of lumbar spine osteoarthritis.

The results of the quartile design variable analysis of the scale of age (see Table 84) are plotted in Figure 31. This plot illustrates a quadratic trend, with an increase in the log-odds for lumbar spine OA from approximately 48 years of age until it peaks at 76 years. The trend then changes direction and declines with increasing age. There was also a significant association detected when choosing to categorise age into: 40-59 years and older than 59 years. GB Olympians older than 59 years were significantly associated with a higher prevalence of OA in the lumbar spine [OR 2.57; 95% CI, 1.09-6.09]. However, this association was no longer significant following the adjustment for the remaining two covariates [aOR 1.02; 95% CI, 0.93-1.12].

Table 84: Results of the Quartile Design Variable Analysis of the Scale of Age

Quartile	1	2	3	4
Range	$x \leq 54$	$55 \leq x \leq 68$	$69 \leq x \leq 82$	$83 \leq x \leq 97$
Midpoint	47	61.5	75.5	90
Coeff.	0.0	1.68	3.36	0.78
95% CI		0.55, 5.10	1.20, 9.47	0.90, 6.86

Values in blue refer to risk factors significantly ($P < 0.05$) associated with the prevalence of lumbar spine osteoarthritis.

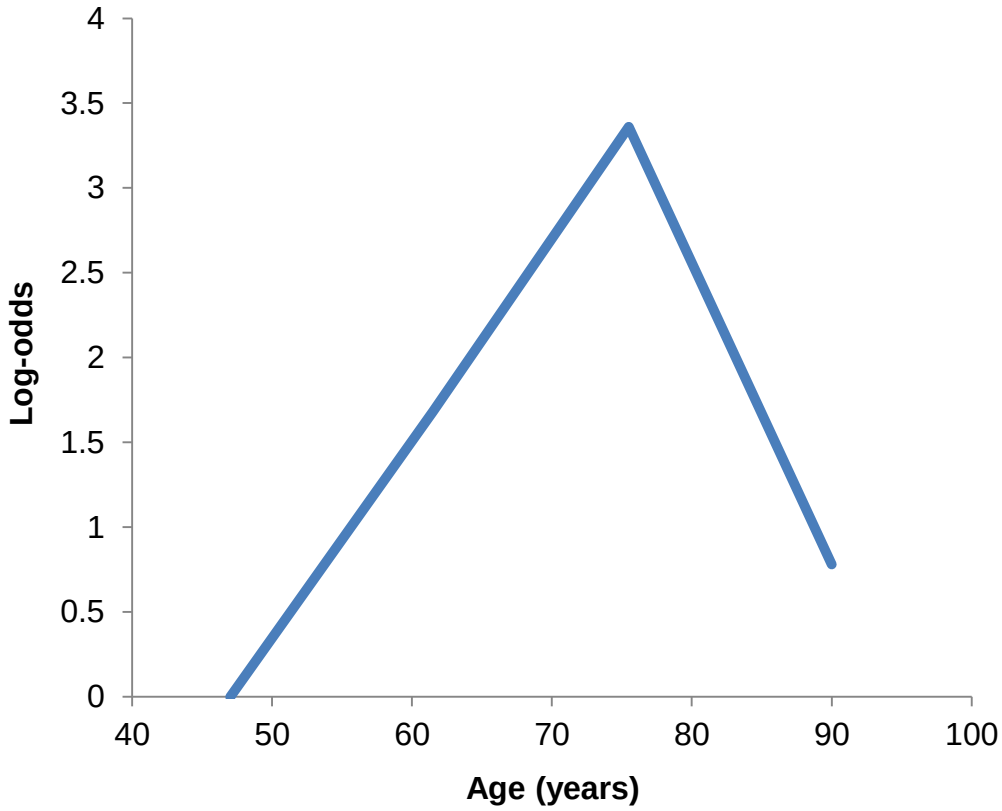


Figure 31: Plot of Estimated Logistic Regression Coefficients for the Quartile Design Variable versus Appropriate Quartile Midpoints of Age in Relation to Lumbar Spine Osteoarthritis

6.2.6.1.2 Body Mass Index

The mean BMI in GB Olympians with lumbar spine OA was marginally greater (M = 24.83 $\pm$ 3.49 kg/m^2) than those with no lumbar spine OA (M = 24.77 $\pm$ 3.70 kg/m^2) (see Table 83). The mean BMI of both those with a history of lumbar spine OA and those without was within the limits of the World Health Organisations (2004) normal BMI category (< 25 kg/m^2). The crude odds ratio of GB Olympians reporting lumbar spine OA was not detected to be significantly associated with a one-unit

increase in BMI (kg/m^2) [OR 1.00; 95% CI, 0.91-1.11]. This was confirmed after adjustment for the remaining covariates in the multivariable regression model [aOR 1.03; 95% CI, 0.93-1.13].

The results of the quartile design variable analysis of the scale of BMI (see Table 85) are plotted in Figure 32. This plot illustrates a linear trend where the log-odds for lumbar spine OA increase from approximately 22 to 34 kg/m^2 and becomes significant at approximately 28.5 kg/m^2. There was no significant association between lumbar spine OA and BMI when categorising into under / normal weight (< 25.00 kg/m^2), overweight ($\geq$ 25 < 30 kg/m^2) [OR 0.99; 95% CI, 0.42-2.36; aOR 1.47; 95% CI, 0.59-3.65], and obese ($\geq$ 30 kg/m^2) [OR 2.23; 95% CI, 0.78-6.37; aOR 2.82; 95% CI, 0.95-8.43].

Table 85: Results of the Quartile Design Variable Analysis of the Scale of Body Mass Index

Quartile	1	2	3	4
Range	$x \leq$ 24.21	24.22 $\leq x \leq$ 30.79	30.80 $\leq x \leq$ 37.36	37.37 $\leq x \leq$ 43.94
Midpoint	20.92	27.51	34.08	40.66
Coeff.	0.0	0.93	1.26	-
95% CI		0.42, 2.04	0.27, 5.80	-

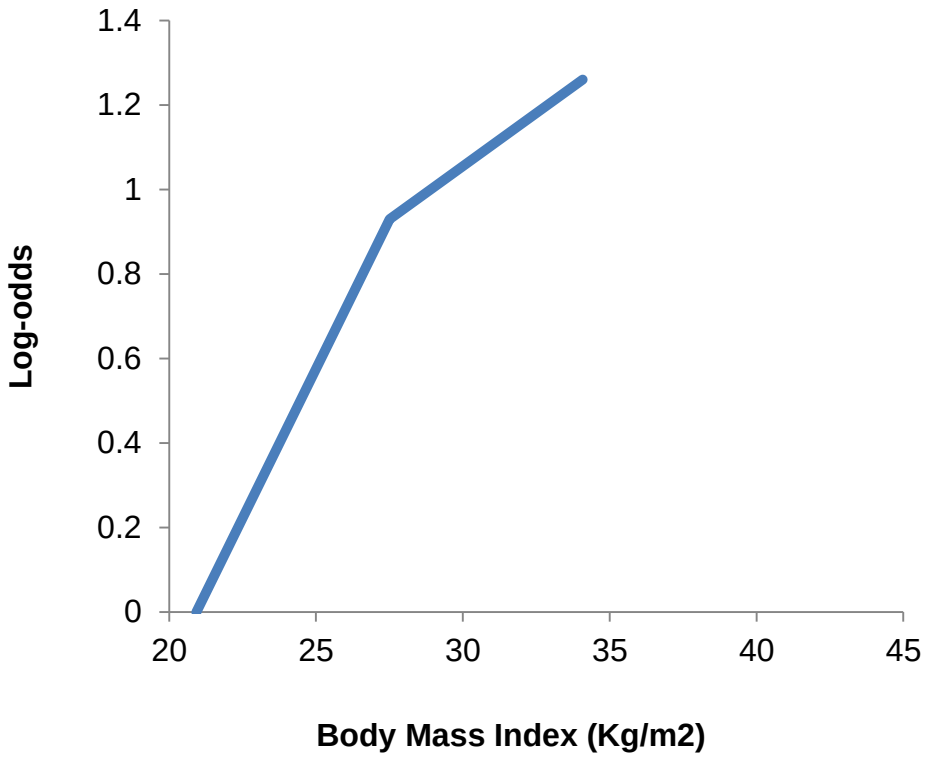


Figure 32: Plot of Estimated Logistic Regression Coefficients for the Quartile Design Variables versus Appropriate Quartile Midpoints of Body Mass Index in Relation to Lumbar Spine Osteoarthritis

6.2.6.1.3 Gender

The prevalence of lumbar spine OA was 3% (9/356) in males and 9% (21/241) in female GB Olympians aged 40 years and older (see Table 86). The risk of lumbar spine OA was significantly greater in female GB Olympians (OR 3.68; 95% CI, 1.66-8.18), and this was confirmed after adjustment for the remaining covariates in the regression model [aOR 5.28; 95% CI, 2.22-12.55].

Table 86: Prevalence of Lumbar Spine Osteoarthritis in Relation to Constitutional Factors (Categorical Independent Variables)

Constitutional factors		Prevalence rate (%)	Odds ratio (95% confidence interval)	
			Crude	Adjusted
Gender:				
Male	9/356	(3%)	**1**	**1**
Female	21/241	(9%)	3.68 (1.66, 8.18)	5.28 (2.22, 12.55)

Values in blue refer to risk factors significantly associated with the prevalence of lumbar spine osteoarthritis.

6.3 Summary of Risk Factors for Pain and Osteoarthritis

The model development began by entering relevant covariates into a series of logistic regression models (see Appendix T: Table 107) to determine if they were associated with pain or osteoarthritis at the hip, knee, and the lumbar spine. A number of risk factors were detected to be significantly associated with the prevalence of musculoskeletal pain following adjustment (see Table 87). Biomechanical risk factors were detected to be significantly associated with pain at the hip (previous significant injury, weight-bearing loading sports), knee (previous significant injury, varus knee alignment in early-life [20-29 years], weight-bearing loading sports), and the lumbar spine (previous significant injury). Constitutional risk factors were shown to be significantly associated with pain at the knee (BMI) and the lumbar spine (age). Widespread pain at two or more joint sites was detected to be significantly associated with pain at the knee. However, widespread

pain was not assessed for an association between pain at the hip or the lumbar spine because the regions of widespread pain overlapped on the body manikin. A self-report of greater physical well-being was significantly associated with a reduced prevalence of pain at the hip, knee and the lumbar spine.

A number of risk factors were detected to be significantly associated with the prevalence of self-reported physician-diagnosed OA following adjustment (see Table 80). Constitutional risk factors (age and gender) were significantly associated with the prevalence of OA at the lumbar spine. Age was also associated with the prevalence of hip and knee OA. The biomechanical risk factor – previous significant injury – was significantly associated with the prevalence of OA at the hip and knee. The two covariates - BMI and early-life [20-29 years] generalised joint hypermobility (GJH) (Beighton $\geq$ 4/9) - were found to be significantly associated with self-reported physician-diagnosed OA at the knee.

Table 87: Risk Factors Significantly Associated with Pain and Self-Reported Physician-Diagnosed Osteoarthritis at the Hip, Knee and the Lumbar Spine

		Risk Factors		
Joint	**Outcome**	**Constitutional**	**Biomechanical**	**Other**
Hip	*Pain*		Previous hip injury Weight-bearing loading sports	Physical well-being
	Osteoarthritis	Age	Previous hip injury	
Knee	*Pain*		Previous knee injury Varus knee alignment [20-29 years] Weight-bearing loading sports Body mass index [20-29 years]	Widespread pain Physical well-being
	Osteoarthritis	Age	Body mass index [20-29 years] Previous knee injury Generalised joint hypermobility (Beighton $\geq$ 4/9) [20-29 years]	
Lumbar spine	*Pain*	Age	Previous lumbar spine injury	Physical well-being
	Osteoarthritis	Age Gender (female)		

7.0 DISCUSSION

7.1 Main Study Findings - The Great Britain's Olympians Study

This is the first study to determine the prevalence and risk factors associated with pain and self-reported physician-diagnosed OA at the hip, knee and the lumbar spine in an elite sporting population. Overall, this study found that: 1) injury appeared to be constantly the strongest risk factor for pain at the knee, hip and the lumbar spine as well as OA at the hip and knee; 2) in GB Olympians aged 40 years and older, the joints most likely affected by OA were the knee (14.2%), hip (11.1%), and the lumbar spine (5%); and the joints most likely affected by pain were also the lumbar spine (32.7%), knee (25.6%), and the hip (23%); 3) participation in weight-bearing loading sports was associated with hip and knee pain, but not hip and knee OA; and 4) generalised joint hypermobility (Beighton $\geq$ 4/9) appeared to be not a risk factor for injury, and nor was it a risk factor for all joint pain/OA except OA at the knee joint.

The results of this study add to the published literature on injury surveillance studies in elite athletes (Engebretsen et al. 2013; Engebretsen et al. 2010). The injury data provides an insight into the types of injuries sustained in current and former elite athletes, both in training and in competition, spanning across several decades. This unique dataset has afforded the opportunity to allow comparisons to be made between the occurrence of injury, and the prevalence of pain and OA in later life. Furthermore, the results of this study add to the

published literature that has examined the prevalence of hip and knee OA in a sporting population (Tveit et al. 2012; Golightly et al. 2009; Chakravarty et al. 2008). The findings expand previous observations of the risk factors that are associated with the onset of knee pain (Ingham et al. 2011; Grotle et al. 2008), and OA (Blagojevic et al. 2010) in the sedentary population. In addition, this study illustrates the risk factors that are associated with pain and OA at the hip and the lumbar spine in an elite sporting population.

7.1.1 Injury, Pain and Osteoarthritis

This study found that the most prominent injury locations for all GB Olympians to be the knee, followed by the lower back, shoulder, and the ankle. In the reviewed sporting literature, the knee, the lower back, and the shoulder were also the most prominent injury locations during the 2010 Winter Olympic Games in Vancouver (Engebretsen et al. 2010). The frequency of head injuries was far greater in GB Olympians who had competed in Winter Olympic sports, compared to those who had competed in Summer Olympic sports. This trend is supported by data in the literature that shows the occurrence of head injuries to be higher in the 2010 Winter Olympic Games in Vancouver (10.5%), compared to the 2009 International Association of Athletics Federations (IAAF) World Championship (1.4%) (Alonso et al. 2010).

The most common significant injury types for all GB Olympians were traumatic fractures, sprain (injury of joint and / or ligaments), and

tendinosis / tendinopathy. Traumatic fractures and sprains were the most common injury types among GB Olympians who had competed in Summer or Winter Olympic sports. Tendinosis / tendinopathy were twice as common among those who had competed in Summer Olympic sports. Yet muscle injury, contusion, concussion, dislocation and subluxation were more frequent among those who had competed in Winter Olympic sports. Trauma related injuries (contusions, concussion, and fractures) are more common in the literature among athletes competing in Winter Olympic sports (Engebretsen et al. 2010), compared to those competing in summer Olympic sports (Alonso et al. 2010).

This study confirms that musculoskeletal pain is a common disorder among GB Olympians aged 40 to 97 years, irrespective of the underlying structural changes associated with OA (see Figure 33). Pain was most prevalent at the lumbar spine (32%; 179/564), the knee joint (26%; 147/564), and the hip joint (22%; 126/564). The trend for pain to be most prevalent at these three joints is supported by general population data in the literature. Hoy et al. (2012) performed a systematic review of the global prevalence of lower back pain and reported a one-month prevalence of 30.8%. Previous studies report that the prevalence of knee pain can vary from 22.4% (Cecchi et al. 2008), 25.1% (Turkiewicz et al. 2015) to 29.0% (Ingham 2010). In the literature reviewed, the prevalence of hip pain is reported to vary from 11.9%

(Cecchi et al. 2008), 14.3% (Christmas et al. 2002) to 20.0% (Ingham 2010).

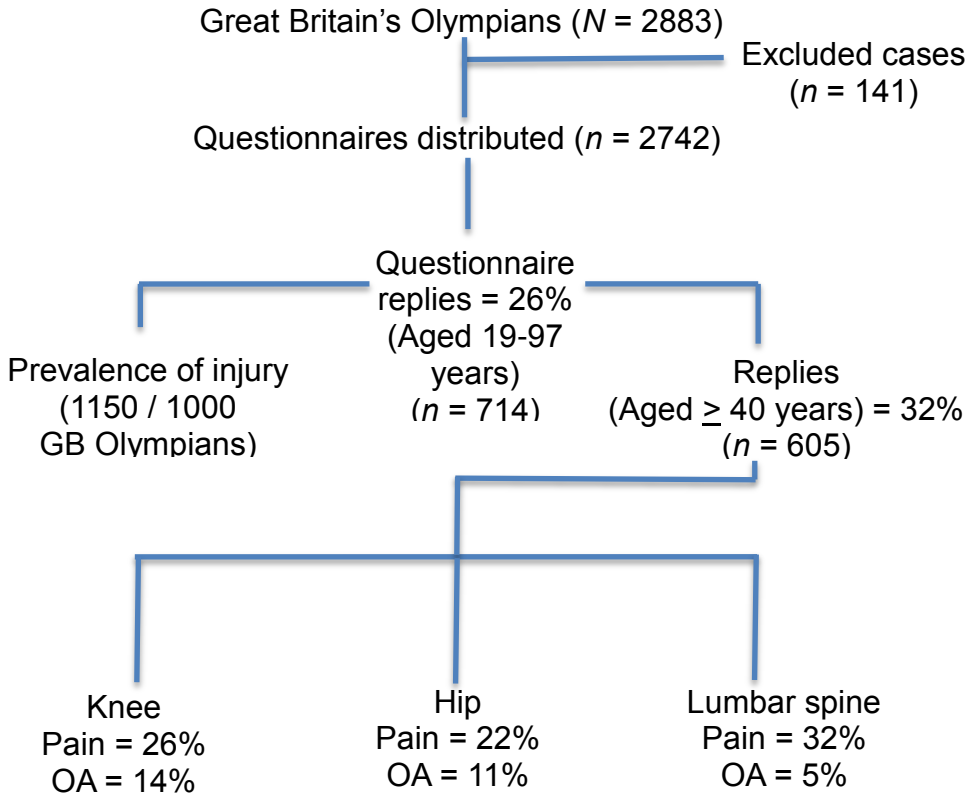


Figure 33: The Prevalence of Injury, Pain and Osteoarthritis

The prevalence of self-reported physician-diagnosed OA in GB Olympians aged 40-97 years was highest at the knee joint (14.2%; 85/597), the hip joint (11.1%; 66/597), and the lumbar spine (5.0%; 30/597). For the hip and knee this is lower compared to 14.2% and 19.4% reported in 664 former male elite athletes (Tveit et al. 2012), and 20.2% and 27.3% in 301 former athletes competing in power sports (boxers, wrestlers, weight lifters, throwers) (Kettunen et al. 2001). The

prevalence of OA was also lower in GB Olympians compared to those reported among former professional football players – 18.8% at the lumbar spine (Turner et al. 2000), 13.2% at the hip joint (Shepard et al. 2003) and 21.3% at the knee (Drawer & Fuller 2001). However, in the reviewed sporting literature, there is substantial difference between studies exploring the prevalence of OA (Gouttebarge et al. 2015). For example, the prevalence of knee OA varied between 21.2% (Kettunen et al. 2001) to 95% among former elite athletes (Nebelung & Wuschech 2005).

There are several potential explanations for differences in the prevalence rate of OA in the reviewed literature. There are different definitions of OA in the literature and different diagnostic criteria, including radiography (Elleuch et al. 2008), arthroscopy (Nebelung & Wuschech 2005), or a self-reported physician-diagnosis (Drawer & Fuller 2001). There are different sports involved in the studies in the literature that may potentially affect the prevalence of OA. There are also variations in methodological procedures with some studies measuring the prevalence rate at each limb (Drawer & Fuller 2001). Whereas other studies measure the prevalence of OA according to the most severe limb (Elleuch et al. 2008).

The different ages of the athletes among the studies reviewed might explain the differences found, and the presence of a significant injury may influence the results, particularly since age and injury are known

risk factors for the onset of OA (Muthuri et al. 2011; Anderson & Loeser 2010). In addition, there is evidence of recruitment bias in some studies where the prevalence rate is only calculated on athletes who had previously sustained a significant joint injury (Nebelung & Wuschech 2005). Furthermore, not all athletes with radiographic evidence of OA are symptomatic. The discordance between radiographic OA and clinical OA makes it difficult to compare results between studies in the literature. These discrepancies in methodological procedures help to explain the variation in the prevalence rates of OA seen in the literature. However, they also prevent reliable comparisons between this study, and the prevalence rates presented in other sporting populations, and those in the general population. A solution would be to undertake a systematic review and to identify the prevalence of OA according to the different varied definitions.

7.1.2 Risk Factors for Pain and Osteoarthritis

A number of factors were detected to be significantly associated with the prevalence of musculoskeletal pain and self-reported physician-diagnosed OA following adjustment (see Table 87). Biomechanical risk factors were the most marked influences of pain at the hip, knee and the lumbar spine, irrespective of the underlying structural changes of OA (see Table 87). Constitutional risk factors were shown to be significantly associated with pain at the knee and the lumbar spine. In addition, widespread pain was found to be significantly associated with pain at the knee. However, this study did not assess whether or not

widespread pain was associated with pain at the hip and the lumbar spine because the areas of widespread pain overlapped on the body manikin. A self-report of superior physical well-being was significantly associated with a reduced prevalence of pain at the hip, knee and the lumbar spine. Biomechanical factors were also major factors in determining an increased risk of hip and knee OA, and constitutional risk factors were especially associated with an increased risk of lumbar spine OA.

7.1.2.1 Constitutional Risk Factors

7.1.2.1.1 Age

This study demonstrates that ageing of the musculoskeletal system plays a significant role in the prevalence of self-reported physician-diagnosed OA at the hip, knee and the lumbar spine. These results are supported by data in previous studies which show age is significantly associated with a higher incidence of physician-diagnosed hip and knee OA (Cheng et al. 2000), and a greater prevalence of symptomatic and radiographic hip OA (Jordan et al. 2007). However, ageing of the musculoskeletal system appeared to play a less significant role in the natural history of the prevalence of recent musculoskeletal pain. Age was significantly associated with lumbar spine pain, but there was no significant association detected between age and pain at the hip and knee.

The findings of this study are in contrast to previous studies which have shown age to be significantly associated with hip pain (Jordan et al. 2007), and knee pain (Hart et al. 1999; Felson et al. 1987). However, the ability to make a direct comparison between studies is limited because of variations in the definition of pain (Jordan et al. 2007; Hart et al. 1999). Furthermore, whereas previous studies tend to explore pain and OA in participants below the age of 80 years (Blagojevic et al. 2010), this study included GB Olympians aged 40 to 97 years of age, with 90 GB Olympians (15%; 90/605) aged 80 years and older. The risk of OA and pain declined in GB Olympians aged 80 years and older. This may explain why no significant association was detected between age and pain at the hip and knee joints.

Interestingly, this study demonstrated that a one-unit decrease in age was detected to be significantly associated with lumbar spine pain in GB Olympians. This particular relationship is explained by the fact that the mean age of those reporting that they had experienced lumbar spine pain recently (*M* = 62.05 + 12.86 years), was lower than those without a recent history of lumbar spine pain (*M* = 64.44 + 13.53 years). Studies in the literature have shown that the prevalence of lower back pain peaks at 60 to 65 years, before declining with further ageing (Hoy et al. 2010). The risk of OA and pain at the hip and knee also peaked, before declining in older age in GB Olympians. It remains unclear why there is a decline in the risk of OA and pain among GB Olympians in later life. This may relate to survival rates, with a superior life

expectancy in those who are able to gain from the health benefits from participation in long-term vigorous exercise, and an inferior life expectancy in those who are less active with comorbidities, such as obesity – a risk factor associated with the onset of OA (Losina et al. 2011). The benefits of long-term vigorous exercise was found to be associated with superior longevity outcomes in elite athletes, particularly in endurance and mixed sports (Lemez & Baker 2015), and is thought to be related to a lower rate of cardiovascular disease (Teramoto & Bungum 2010).

Although survival rates may help to explain the decline in the risk of OA and pain in older age, this theory is contrary to some reports in the literature. Liu et al (2015) found that patients consulting health care practitioners for OA are at no greater risk of death. However, this study included only a limited number of cases of OA, and it also excluded patients beyond 74 years of age. In a separate analysis, the prevalence of pain at the hip and lumbar spine was greatest in GB Olympians younger than 40. Yet the prevalence of self-reported physician-diagnosed OA was virtually non-existent in this age group. These findings imply that there are different pathological processes responsible for pain between younger and older GB Olympians, and these pathways appear to vary according to the joint under examination. This is consistent with current thinking about the aetiology of OA that describes different phenotypes of the disease (Van Der Esch et al. 2015).

The prevalence of low back pain in the sedentary population is reported to be highest during middle age, and is thought to reflect the most productive years of a person's working life (Jones et al. 2006). Similarly, the peak in the prevalence of lumbar spine pain in the younger GB Olympians may reflect their most competitive years in sport. The peak in lumbar spine pain in early-life and then in later life may relate to different pathology. This bi-modal distribution may be explained by injury being related to lumbar spine pain early on, with the onset of OA related to lumbar spine in later life. However, it is difficult to understand why the prevalence of low back pain peaks again at 62 years, before declining with increasing age, particularly when the prevalence of OA, disc degeneration and osteoporosis are known to increase with ageing (Dionne et al. 2006). The decline in the prevalence of pain among the elderly may result from a reluctance to report pain because of a fear that pain is indicative of severe pathology (Keela & Garand 2001). In addition, pain may also be underreported because the elderly population expect pain with aging, and cognitive impairment puts this segment of the population at greatest risk for the under-recognition of pain (Parmelee 1996).

7.1.2.1.2 Gender

Previous studies have shown that females have a greater risk of knee pain (Jinks et al. 2008; Hart et al. 1999), and more severe radiographic knee OA (Felson et al. 1987), particularly after 55 years of age

(Srikanth et al. 2005). This is thought to reflect the effect of estrogen deficiency following the menopause. Cicuttini et al (1997) has shown in a cross-sectional study of middle-aged females that the effect of oestrogen reduced OA at the patello-femoral joint but not at the tibio-femoral joint. It is possible that the effect of female gender is site specific, and, if so, this may explain why there was a significant association detected between OA and female gender at the lumbar spine, but not at the hip or knee in GB Olympians. This study did not distinguish between OA at the patello-femoral and the tibio-femoral joint. In addition, many of the female GB Olympians in this study were at a pre-menopausal age. They could therefore be considered to be at a lesser risk of experiencing knee pain and OA than post-menopausal females. However, this study did not assess bone mineral density to determine if GB Olympians were different from the normal population.

7.1.2.1.3 Body Mass Index

Previous studies have shown that a high body mass index is a risk factor for a higher prevalence of knee OA (Losina et al. 2011; Cooper et al. 2000; Hochberg et al. 1995), and knee pain (Jinks et al. 2008). Consistent with these observations, this study also detected a significant association between BMI and knee pain, and BMI and knee OA. Of the GB Olympians aged 40 years and older with pain and OA at the knee, the mean BMI was within the limits of the World Health Organisation (2004) overweight category ($\geq$ 25, < 30 kg/m^2). Conversely, the mean BMI in GB Olympians without knee pain or knee

OA was within the limits of the normal BMI category (< 25 kg/m^2). However, the log-odds for knee pain and OA in GB Olympians peaked at 34kg/m^2, and a plateau was followed with increasing levels of obesity. This plateau is probably a result of a limited number of events of OA in GB Olympians who have a BMI of $\geq$ 33 kg/m^2.

When BMI was analysed in a category form, as is often the case in the literature, there was a significant association detected between obesity ($\geq$ 30.00 kg/m^2), and pain and OA at the knee joint in GB Olympians aged 59 years and older. The link between the onset of knee pain and structural body weight could be explained by a biomechanical effect, with increased mechanical stress being a potential cause of cartilage breakdown and knee OA (Felson 1995). However, research has also shown an association between obesity and hand OA (Grotle et al. 2008), and this may represent a metabolic or inflammatory role of obesity (Allen & Golightly 2015). Studies have found evidence of a metabolic inflammatory pathway, with the association between BMI and knee OA explained by higher leptin levels (Karvonen-Gutierrez et al. 2014; Fowler-Brown et al. 2015).

7.1.2.2 Biomechanical Risk Factors

7.1.2.2.1 Previous Joint Injury

Traumatic injury is a major risk factor for the development of OA and musculoskeletal symptoms, particularly at the knee (Muthuri et al. 2011; Toivanen et al. 2010; Miranda et al. 2002). A traumatic joint injury was

reported to be associated with ankle OA (Valderrabano et al. 2009), and ligamentous lesions have also been shown to be associated with the onset of post-traumatic ankle OA (Valderrabano et al. 2006). Meniscal injuries, dislocations, fractures and cruciate ligament tears can result in an increased risk of knee OA (Litwic et al. 2013). Patients with anterior cruciate ligament deficiency and reconstruction were shown to have altered synovial fluid biomarker levels indicative of OA (Harkey et al. 2015). Direct trauma to tissue can also disrupt normal joint kinematics. This results in altered load distribution within the joint, which contributes to the initiation of OA (Litwic et al. 2013).

The results of this study also found that a previous history of a significant traumatic joint injury was a major risk factor associated with the prevalence of pain and OA (see Table 87). Joint injury was associated with pain and OA at all three joint sites except OA at the lumbar spine, where it was excluded from the analysis because of a limited number of outcomes of the disease. GB Olympians with knee pain and OA were more likely to report cartilage injuries, joint sprain (injury of joint and / or ligaments), and ligament ruptures. The injuries most frequently reported in GB Olympians with lumbar spine OA consisted of disc injuries, contusions and joint related injury. GB Olympians with lumbar spine pain were more likely to report that they had suffered injuries to the intervertebral disc, muscle, joint related injuries, and fractures.

All the knee cartilage injuries sustained in competition or training in GB Olympians aged 40 years and older were associated with weight-bearing loading exercise. Approximately 90% of knee ligament ruptures and 92% of knee joint sprains were sustained through participation in weight-bearing loading exercise. GB Olympians who had participated in weight-bearing loading Olympic sports were detected to have a significantly higher risk of reporting hip and knee pain. Weight-bearing sports activity in females was previously reported to be associated with a two-to-three fold increase in the risk of radiographic OA at the hip and knee, and similar rates of symptoms were reported between ex-athletes and controls (Spector et al. 1996). Further research would help to determine if substituting weight-bearing physical activities in an athletes' training schedule, with forms of non-weight bearing physical activity, can reduce the risk of significant joint injury, and the subsequent risk of OA.

7.1.2.2.2 Impact Sport

Tveit et al (2012) demonstrated that male athletes who participated in impact (i.e. contact) sports at an elite level had an increased prevalence of OA in the hip and knee joints, following adjustment for age and injury, compared to elite athletes who were registered as having participated in non-impact sports. This study detected no significant association between impact sport and pain at the hip, knee and the lumbar spine. Furthermore, there was no significant association detected between impact sport and OA at the hip joint and the lumbar spine. Although

there was an association detected between knee OA and impact sport, this association was no longer significant after adjusting for age, injury, BMI, gender, and GJH.

7.1.2.2.3. Knee Mal-alignment

Previous studies have confirmed that varus knee mal-alignment was associated with the onset of radiographic knee OA (K/L $\geq$ 2) at the tibiofemoral joint (Brouwer et al. 2007). It is perceived that varus mal-alignment of the knee may contribute to cartilage degeneration through an alteration in the load distribution acting across the articular surfaces of the tibiofemoral joint (Litwic et al. 2013). The results from this study indicate that early-life (20-29 years) varus knee mal-alignment was significantly associated with the prevalence of knee pain, but not knee OA in GB Olympians aged 40 years and older. The lack of an association between varus knee mal-alignment and knee OA is possibly due to the fact that this study collected data retrospectively. The results of this study are therefore subject to potential recall bias. In comparison, Brouwer et al (2007) collected data by measuring the femorotibial angle on radiographs at baseline and follow-up, and OA was defined radiographically. The use of radiographic evidence to detect OA is known to increase the prevalence of the disease, thereby making it easier to detect any association where one exists. However, this study used a self-report physician-diagnosis of OA, making it more difficult to detect. In addition, this study collected data using a suboptimal measure of knee mal-alignment. The results of this study are therefore

subject to potential measurement bias.

7.1.2.2.4 Generalised Joint Hypermobility

To date, a correlation between joint hypermobility and OA has been shown to be possible. It remains unproven, however, whether joint hypermobility acts as a risk factor or protector for the onset of OA and whether this varies between joints. For example, Kraus et al. (2004) reported a negative association with OA at the proximal phalangeal joints. However, Scott et al. (1979) compared 50 females with symptomatic OA involving at least three joints (knees, hips, shoulders, hands, cervical spine and / or lumbar spine) with an age-matched control group and found joint hypermobility (Beighton $\geq$ 4/9) to be significantly higher ($P < 0.05$) in the OA group (24%). This is further evidence that joint hypermobility is associated with OA at the 1st carpometacarpal joint (Jónsson et al. 2009; Jonsson et al. 1996; Jonsson & Valtysdottir 1995). However, these studies have not controlled for confounders in the statistical analysis.

After controlling for confounders, this study found that GJH (Beighton > 4/9) in early-life (20-29 years) was not detected to be a risk factor or protector for all joint pain/OA, with the exception of knee OA in GB Olympians aged 40 years and older. Furthermore, GJH in early-life was a risk factor for knee OA, independent of a previous significant injury to the knee joint. Previous studies have found that sports participants with GJH have an increased risk of knee joint injury during contact activities

(Pacey et al. 2010). However, the results from this study indicated that GB Olympians with GJH were not detected to be either at a greater or lesser risk of joint injury. However, this study only included significant joint injuries and the findings do not indicate whether or not those with GJH are more or less likely to sustain minor or multiple injuries at the same joint site. The findings of this study demonstrate an association between GJH in early-life (20-29 years) in GB Olympians and knee OA in later life. This is thought to be due to a hypermobile knee joint exerting greater biomechanical stresses on articular cartilage. It remains unclear if knee OA in those with GJH is related to a new unique molecular phenotype associated with a higher ratio of elastic type III collagen.

7.1.2.3 Other Risk Factors

7.1.2.3.1 Widespread Pain

Widespread pain was recorded if an individual had axial pain plus pain in at least two sections of each of two contralateral quadrants of the body, a method previously recommended by Thomas et al. (2004). Widespread pain was detected to be significantly associated with knee pain in GB Olympians aged 40 years and older. However, widespread pain was not included in the univariable regression models for the risk factors associated with pain/OA at other joint sites because the regions of widespread pain overlapped with the region of hip pain, and lumbar spine pain.

The association between widespread pain and knee pain in GB Olympians indicates that knee pain may be part of shared pathology, such as generalized OA or a pain processing disorder. Widespread pain is also seen in the presence of structural pathology including various forms of polyarthritis, connective tissue disorders, polymyalgia rheumatica, vasculitis, sarcoidosis, chronic viral diseases, and metabolic diseases such as hypothyroidism (Yunus 2007). Chronic widespread pain when present in the absence of structural pathology may reflect central sensitization - an abnormality in central pain processing. Pain processing disorders are reported to reflect deficiencies in serotonergic and noradrenergic transmission in the central nervous system. The heightened state of pain transmission has also been attributed activation of N-methyl-D-aspartate receptors on wide-dynamic-range neurons that can cause additional release of neuropeptides such as substance P. These substances can diffuse in the spinal cord and result in the spread of pain (Nielsen & Henriksson 2007).

Chronic widespread pain combined with widespread allodynia/hyperalgesia is also seen in disorders such as fibromyalgia syndrome (Nielsen & Henriksson 2007). The presence of chronic widespread pain with or without allodynia/hyperalgesia may induce a state of hyperexcitability in the spinal cord. This may result in proximal and distal referral of symptoms, compared to the predominant distal referral seen in otherwise healthy tissue (Nielsen & Henriksson 2007).

This would mean that knee pain might also be a product of referred pain from spinal nerves in a dermatomal pattern, the viscera, and other surrounding muscles, both proximal and distal to the joint site.

This study found that GB Olympians with a greater sense of physical limitation were more likely to report pain at the hip, knee and the lumbar spine. Similarly widespread pain and physical limitation were found to be associated with the onset of knee pain and depression in patients registered at three general practices in North Staffordshire, UK (Jinks et al. 2008). However, depression was not detected to be associated with knee pain in GB Olympians. This would suggest that mental well-being was not associated with knee pain through central sensitization of pain. Previous studies have found that pain at the hip, and the lumbar spine were a significant risk factor for the onset of knee pain (Cecchi et al. 2008; Jinks et al. 2008). However, single sites of pain including hip and lumbar spine pain were investigated separately for any association with knee pain, and no associations were found after adjustment in GB Olympians.

7.1.2.3.2 Index Ring Finger Ratio

Zhang et al (2008) found that individuals with male patterning (i.e. type III – index finger shorter than ring finger) are at greater risk of knee OA than those with a different finger patterning. This study found no association between index ring finger length and the prevalence of OA. This lack of association may be due to this study using a self-report

instrument compared to Zhang et al (2008) who used a radiographic measurement to determine the index ring finger ratio.

7.1.2.3.3 Finger Nodes

Finger nodes were found to have an effect on lumbar spine pain and knee OA. However, this association was no longer significant after adjustment. Comorbidity risk factor (those suffering from two or more comorbidities) was found to be associated with pain and OA at the hip and knee. This risk factor was no longer significant after adjustment had been made for the other factors in the multivariable regression model.

7.2 Limitations of the Olympian Study

This study contained several caveats. A large proportion of female GB Olympians were considered to be premenopausal, and this may explain why no association was detected between female gender, and hip and knee OA. Furthermore, a self-reported physician-diagnosis of OA cannot, without radiographic evidence, accurately differentiate between periarticular structures. GB Olympians were not able to take part in a small validation study to determine if there was agreement between physician-diagnosed OA and a standard clinical assessment. Previous studies suggest that self-report definitions of OA may underestimate the burden of disease (Litwic et al. 2013). The ability to compare results across studies was limited because in the literature there is no uniform definition of lumbar spine, hip and knee pain, and previous studies have a tendency to use different GJH cut-off points.

Many studies in the literature choose to categorize age and BMI assuming that everyone above or below the cut-off is equal. This limits the ability to make comparisons between studies that use different cut-points. Other studies assume that age and BMI are linear in the regression model. Analysis of the quartile design variables demonstrated that age and BMI were not always linear. This study analysed age and BMI in a category and continuous form to allow for comparison with previous studies. The use of BMI was potentially misleading; triceps-skinfold thickness (peripheral fat) in males and the waist-hip ratio (central fat) in females were demonstrated to be more strongly associated with knee OA than BMI (Sanghi et al. 2011). Body mass index is unable to discriminate between muscle and adipose tissue, which may be particularly pertinent in a sporting elite, or retired elite population, and it cannot directly assess regional adiposity (Stevens et al. 2008). In addition, BMI is affected by higher bone mass (seen in some athletics populations) and those of African descent (Micklesfield et al. 2003). The discordance between the prevalence of OA and pain in the younger and older GB Olympians implies that OA was not the driving force behind pain. Further investigations would be required in order to determine the cause of pain in GB Olympians.

The study design was able to determine in the literature the prevalence of pain and OA efficiently, and was relatively cheap to undertake in comparison to cohort and intervention studies. An internal nested case-

control study was useful at identifying associations that can be more rigorously investigated, using a cohort study or randomised controlled trial. However, the study design was unable to assess the direction of causality, and it was subject to a number of biases, including confounding, recall, and selection bias (Mann 2003). GB Olympians were requested to recall any previous significant injuries, and early-life (20-29 years) varus knee mal-alignment, BMI, and joint hypermobility. This may have resulted in either an underestimate or overestimate of the association between exposure and outcome (Mann 2003). The self-report measure of joint hypermobility used in this study was shown to be comparable to clinical assessment, but asking GB Olympians to estimate their joint range in their twenties, retrospectively was subject to potential recall bias.

This study limited the potential for recruitment bias by making strenuous efforts to achieve a high response rate. All GB Olympians on the BOA Olympian database - including those living in the UK, and overseas - were invited to participate in the study. The invitation letter emphasised the importance of all athletes responding, irrespective of whether or not they were still competing, or they had experienced pain and OA, as all responses were equally important. An adjusted estimate was used to reflect the degree of association that remained between the exposure and disease, after the effects of the confounder had been removed. However, a limited number of outcomes of lumbar spine OA may have prevented further associations from being detected, and this may have

led to erroneous conclusions (Skelly et al. 2012).

7.3 Recommendations for Future Research

A secondary analysis of the Olympian study dataset with matched controls would help to determine if the risk of OA, pain and arthroplasty is greater in GB Olympians than in the general population. In addition, the relationship between pain and OA at the hip, knee, and the lumbar spine may be improved with further population-based studies in the areas of biomarkers and pain pathways. More attention should be paid to the prevalence of pain, particularly in the elderly population, given that currently the problem tends to be examined in those of working age. Further intervention studies may help to determine if non-weight-bearing loading exercise is capable of reducing the prevalence of hip and knee pain in the general population. This type of exercise may need to be stratified according to the underlying pathology, including the structural stage of OA.

There is a need for a user-friendly evidence-based instrument that can be used in the clinical setting and accounts for the joints most commonly affected by joint hypermobility. In addition, this instrument needs to be accompanied by specific descriptions of the procedures to perform these tasks. A prospective cohort study is required to determine if GJH is associated with knee OA in the general population, particularly among females. A measure of joint hypermobility is already being undertaken in the Significant Ankle Ligament Longitudinal Cohort

Study and will be used to determine any links between injury, pain and OA in the general population. Future cohort studies are required to determine how to adjust the cut-off threshold for defining GJH according to age, gender, and ethnicity.

7.4 Conclusion

This study found that the knee (14.2%) is most likely affected by OA in GB Olympians, followed by the hip (11.1%), and the lumbar spine (5%); and the lumbar spine (32.7%) is most likely affected by pain, followed by the knee (25.6%), and the hip (23%). Injury appeared to be constantly the strongest risk factor for pain at the lumbar spine, the knee and the hip joint, as well as OA at the hip and knee joints. In addition, participation in weight-bearing loading sports was associated with hip and knee pain, but not hip and knee OA; and generalised joint hypermobility (Beighton $\geq$ 4/9) appeared to be not a risk factor for injury, and nor was it a protector or risk factor for all joint pain/OA except OA at the knee joint. An increase in BMI was associated with knee pain/OA, and varus knee mal-alignment was also associated with knee pain. Ageing was associated with OA at the hip, knee and the lumbar spine, but it was not associated with joint pain, except at the lumbar spine. A greater sense of physical well-being was associated with a lower risk of pain at the hip, knee and the lumbar spine.

There appeared to be a bi-modal distribution of pain in younger versus older GB Olympians, and this may be explained by injury being related

to joint pain early on, with the onset of OA related to joint pain in later life. The prevalence of knee pain may in part be related to knee OA pathology, but it may also represent a wider pain problem, such as pain central sensitisation. This study recommends future research to confirm that GJH is not a risk factor for all joint pain/OA, except knee OA among the general population and particularly among females. As one of the few modifiable risk factors, joint injury prevention should be part of the future initiatives to reduce the risk of OA, along with maintaining a healthy body weight.

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APPENDIX A: Contompasis Scoring System

Test 1: Passive opposition of the thumb to the flexor aspect of the forearm (thumb to wrist test).

2 points = thumb bends 30-75 degrees (no touch to forearm)

4 points = thumb touches forearm

5 points = thumb digs into forearm easily

6 points = thumb overlaps outside of forearm

Test 2: Passive dorsiflexion of the fifth metacarpalphalangeal joint.

2 points = 30 to 85 degrees

4 points = 100 to 120 degrees

5 points = 100 to 120 degrees

6 points = 120 degrees and over

Test 3: Passive hyperextension of the elbow

2 points = 0 to 5 degrees

4 points = 10 to 16 degrees

5 points = 16 to 20 degrees

6 points = 20 degrees and over

Test 4: Passive hyperextension of the knee

2 points = 0 to 5 degrees

4 points = 10 to 16 degrees

5 points = 16 to 20 degrees

6 points = 20 degrees and over

Test 5: Hyper flexibility of the spinal column

2 points = no contact with the ground

4 points = fingers touching the ground

5 points = fingers touching the ground

6 points = palms to the ground

7 or 8 points = wrists or forearm to ground

Test 6: Foot flexibility test

2 points = 0 to 2 degrees of eversion

4 points = 3 to 5 degrees eversion of calcaneus

5 points = 6 to 10 degrees eversion of calcaneus

6 points = 10 to 15 degrees eversion of calcaneus

8 points = 15 degrees and up eversion of calcaneus

NB: A score of 22 points indicate no joint hypermobility. The highest score of 72 points indicate the highest level of joint hypermobility.

APPENDIX B: Example of Literature Search

1. Cohort study [Title/Abstract] (987 271)

2. Prospective study [Title/Abstract] (102 819)

3. Prevalence [Title/Abstract] (410 999)

4. Relative risk [Title/Abstract] (48 611]

5. Cross sectional [Title/Abstract] (255 666)

6. 1 or 2 or 3 or 4 or 5 or 6 (675 766)

7. Knee osteoarthritis [Title/Abstract] (5127)

8. Knee pain [Title/Abstract] (4450)

9. Knee arthritis [Title/Abstract] (437)

10. Knee osteoarthrosis [Title/Abstract] (59)

11. Osteoarthritis [Title/Abstract] (38 730)

12. Osteoarthrosis [Title/Abstract] (2 920)

13. Joint space narrowing [Title/Abstract] (1198)

14. Osteophyte [Title/Abstract] (1379)

15. Degenerative joint disease [Title/Abstract] (1773)

16. 11 or 12 or 13 or 14 or 15 (43 988)

17. Knee pain [Title/Abstract] (4450)

18. 16 and 17 (1432)

19. 7 or 8 or 9 or 10 or 18 (9345)

20. 6 and 19 (1182)

21. Knee injury [Title/Abstract] (29 905)

22. 20 and 21 (82)

23. Occupation or physical activity [Title/Abstract] (348 001)

24. 20 and 23 [182]

APPENDIX C: Advert for the Study

Injury Patterns & the Development of Osteoarthritis in GB Olympians

The University of Nottingham is working in collaboration with Arthritis Research UK (ARUK), and with the support of the British Olympic Association (BOA) and BOA Athletes' Commission, to undertake a study of osteoarthritis in Great Britain's Olympians.

As an Olympian, you will be invited to participate in the study and will be sent a questionnaire in the Spring to gather information on your sporting history, injury episodes, and symptoms (or absence thereof) of osteoarthritis.

The information collected will be analysed to determine any trends associated with injury, and those who go on the develop symptoms of osteoarthritis, but also importantly those who do not; with the potential for guideline development for the treatment and prevention of osteoarthritis in later life for Great Britain's Olympians.

Your contribution to this research will be invaluable, to improve the knowledge and understanding of this condition in elite athletes, to the potential benefit of yourself, your sport and Great Britain sport as a whole.

Many thanks in advance.

Mark Batt – Director, ARUK Centre for Sport, Exercise and Osteoarthritis

Mark England – Director of Sport Services, British Olympic Association

Sarah Winckless – Chair, BOA Athletes' Commission

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

Arthritis Research UK | centre for sport, exercise & osteoarthritis

APPENDIX D: UK Letter of Invitation

Dear Sir / Madam, May 2014

The Olympian Study
Protecting Olympic athletes from osteoarthritis

We are undertaking a study of osteoarthritis in Great Britain's (GB) Olympians. This should provide important information on this common and often disabling condition.

We are inviting you as a current or former GB Olympic athlete to participate in this study. This will involve completing a questionnaire that will take approximately 20 minutes of your time. We need information from athletes who have symptoms of osteoarthritis and those who do not. **Your reply will prove very valuable to this study regardless of whether or not you have any symptoms. Your responses will be kept strictly confidential and you will not be identified in anyway.**

I have attached an information sheet that explains this study in more detail. Please read through this at your convenience and discuss it with your friends and family if you wish. The completion of the questionnaire is completely voluntary and should you choose to return a completed questionnaire it implies you have consented to participate. If you decide not to participate this will in no way affect any future treatment you receive at your local hospital or local GP surgery.

The Centre for Sport, Exercise and Osteoarthritis at the University of Nottingham is working in collaboration with Arthritis Research UK and is conducting many studies into sport, exercise and arthritis to help improve knowledge and understanding of this disabling condition. Such studies require the voluntary co-operation of people such as you.

If you have read through the information sheet and have decided that you would like to participate, please complete the enclosed paper questionnaire and return it using the prepaid envelope provided, or alternatively you may complete the questionnaire online at **https://www.survey.bris.ac.uk/nottingham/olympians** using your identification number as shown on the sticky label at the top of this letter.

Thank you for taking the time to read this information. We look forward to hearing from you.

Yours faithfully,

Professor Mark Batt
Director ARUK Centre for Sport, Exercise and Osteoarthritis

Sarah Winckless
British Olympic Association Athletes' Commission Chair

Enclosed: Participant information leaflet; Questionnaire, pre-paid envelope.

Arthritis Research UK | centre for sport, exercise & osteoarthritis

Centre for Sport, Exercise & Osteoarthritis
Nottingham University Hospitals NHS Trust
Queens Medical Centre
C floor, West Block
Derby Road
Nottingham
NG7 2UH
www.sportsarthritisresearchuk.org

Arthritis Research UK | centre for sport, exercise & osteoarthritis

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

APPENDIX E: Overseas Letter of Invitation

Dear Sir / Madam, August 2014

The Olympian Study
Protecting Olympic athletes from osteoarthritis

We are undertaking a study of osteoarthritis in Great Britain's (GB) Olympians. This should provide important information on this common and often disabling condition.

We are inviting you as a current or former GB Olympic athlete to participate in this study. This will involve completing a questionnaire that will take approximately 20 minutes of your time. We need information from athletes who have symptoms of osteoarthritis and those who do not. **Your reply will prove very valuable to this study regardless of whether or not you have any symptoms. Your responses will be kept strictly confidential and you will not be identified in anyway.**

I have enclosed an information sheet that explains this study in more detail. Please read through this at your convenience and discuss it with your friends and family if you wish. The completion of the questionnaire is completely voluntary and should you choose to return a completed questionnaire it implies you have consented to participate. If you decide not to participate this will in no way affect any future treatment you receive at your local hospital or local GP surgery.

The Centre for Sport, Exercise and Osteoarthritis at the University of Nottingham is working in collaboration with Arthritis Research UK and is conducting many studies into sport, exercise and arthritis to help improve knowledge and understanding of this disabling condition. Such studies require the voluntary co-operation of people such as you.

If you have read through the enclosed information sheet and have decided that you would like to participate, please complete the paper questionnaire and return it to the address below. Please note we are unable to provide the correct postage for a prepaid envelope to those of you living outside of the UK but we are willing to reimburse you the full cost of posting it to us. Should you wish to claim the cost of the return postage please contact Dale Cooper by email at msxdjc@exmail.nottingham.ac.uk. Alternatively, you may complete the questionnaire online at **https://www.survey.bris.ac.uk/nottingham/olympians** using your identification number as shown on the sticky label at the top of this letter.

Thank you for taking the time to read this information. We look forward to hearing from you.

Yours faithfully,

Professor Mark Batt
Director ARUK Centre for Sport, Exercise and Osteoarthritis

Sarah Winckless
British Olympic Association
Athletes Commission Chair

Enclosed: Survey information leaflet; Questionnaire.

Arthritis Research UK | centre for sport, exercise & osteoarthritis

Centre for Sport, Exercise & Osteoarthritis
Nottingham University Hospitals NHS Trust
Queens Medical Centre
C floor, West Block
Derby Road
Nottingham
NG7 2UH
www.sportsarthritisresearchuk.org

Faculty of Medicine & Health Sciences 304

APPENDIX F: Invitation Sent by Email

Dear X

Re: The Olympian Study

We are undertaking a study of osteoarthritis in Great Britain's (GB) Olympians. This should provide important information on this common and often disabling condition.

We are inviting you as a current or former GB Olympic athlete to participate in this study. This will involve completing a questionnaire that will take approximately 20 minutes of your time. We need information from athletes who have symptoms of osteoarthritis and those who do not. Your reply will prove very valuable to this study regardless of whether or not you have any symptoms. Your responses will be kept strictly confidential and you will not be identified in anyway.

Please read the participation information sheet for further details by clicking on the following link: http://www.sportsarthritisresearchuk.org/seoa/documents/olympics/participant-information-may.pdf. Please read through this at your convenience and discuss it with your friends and family if you wish. The completion of the questionnaire is completely voluntary and should you choose to return a completed questionnaire it implies you have consented to participate. If you decide not to participate, this will in no way affect any future treatment you receive at your local hospital or local GP surgery.

The Centre for Sport, Exercise and Osteoarthritis at the University of Nottingham is working in collaboration with Arthritis Research UK and is conducting many studies into sport, exercise and arthritis to help improve knowledge and understanding of this disabling condition. Such studies require the voluntary co-operation of people such as you.

If you have read through the information sheet and have decided that you would like to participate, please complete the questionnaire online at https://www.survey.bris.ac.uk/nottingham/olympians using your identification number as shown at the top of this email.

Thank you for taking the time to read this information. We look forward to hearing from you.

Yours sincerely

Sarah Winckless
Chair of the Athletes' Commission
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APPENDIX G: Olympian Questionnaire: Paper-Version

centre for sport, exercise & osteoarthritis

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

The Olympian Study

The University of Nottingham is working in collaboration with Arthritis Research UK (ARUK), and with the support of the British Olympic Association (BOA) and BOA Athletes Commission, to undertake a study of osteoarthritis in Great Britain's Olympic Athletes.

As an Olympian, you have been invited to complete the **Olympian Questionnaire**. The questionnaire takes 20 minutes to complete. The information collected will be analysed to determine any trends associated with injury, and those who go on to develop symptoms of osteoarthritis, but also importantly those who do not; with the potential for guideline development for the treatment and prevention of osteoarthritis in later life for Great Britain's Olympic Athletes.

Your contribution to this research will be invaluable, to improve the knowledge and understanding of this condition in elite athletes, to the potential benefit of yourself, your sport and Great Britain sport as a whole. **Your responses will be kept strictly confidential and you will not be identified.**

Many thanks in advance.

Professor Mark Batt
Director ARUK Centre for Sport, Exercise and Osteoarthritis

Sarah Winckless -
British Olympic Association
Athletes Commission Chair

INSTRUCTIONS FOR COMPLETING THIS QUESTIONNAIRE

Please complete the questionnaire as accurately as possible, and please use your best estimate in situations where you are unsure. There are no right or wrong answers.

Most questions can be answered by putting a tick in the appropriate box, e.g. ✔

On completing the questionnaire you will be entered into a free prize draw of two tickets to a sporting event. If you do not wish to be entered please tick this box ☐

Please return this questionnaire in the pre-paid envelope provided. **You do not need a stamp.** Alternatively you may complete the questionnaire online at:

https://www.survey.bris.ac.uk/nottingham/olympians

If you have any questions about this questionnaire or the study in general, you can contact Dale Cooper on 0115 8231411 or by email at: msxdjc@exmail.nottingham.ac.uk

Section one - about you

1.1 What is your **gender**? *(Please tick)* Male ☐ Female ☐

1.2 What **year** were you born? *(E.g. 1965)* ☐☐☐☐

1.3 What is your **height**? *(Without shoes)*

☐ *Feet* ☐☐ *Inches* **OR** ☐☐☐ *Centimetres*

1.4 What is your **current weight**? *(light clothing only)*

☐☐ *Stones* ☐☐ *Pounds* **OR** ☐☐☐ *Kilograms*

1.5 How much did you **weigh in your 20's**? *(If you are currently in your 20s please move to the next question)*

☐☐ *Stones* ☐☐ *Pounds* **OR** ☐☐☐ *Kilograms*

1.6 Which **ethnic** group best describes you? *(Please tick)*

☐ .... White (English, Welsh, Scottish, British, Northern Irish)

☐ .... Black African

☐ .... Black British

☐ .... Black Caribbean

☐ .... Other, please specify .....

☐ .... Mixed (White & Black African)

☐ .... Mixed (White & Asian)

☐ .... Mixed (White & Black Caribbean)

☐ .... Asian / Asian British (Indian, Pakistani, Bangladeshi, Chinese)

1.7 Which is your **dominant limb/s** for participating in your athletic sports career? *(Please tick)*

	Right	Left	Equally Proficient
Upper limb (arm / hand)	☐	☐	☐
Lower limb (leg / foot)	☐	☐	☐

1.8 Are you **retired** from your athletic sports career? Yes ☐

No ☐ *(If no, please move to question 1.11)*

9.5 During the **past 4 weeks** how much did **pain** interfere with your normal work (including both work outside the home and housework)?

Not at all ☐ A little bit ☐ Moderately ☐ Quite a bit ☐ Extremely ☐

9.6 These next questions are about how you feel and how things have been with you **during the past 4 weeks.** For each question, please give the one answer that is closest to the way you have been feeling. How much of the time during the past 4 weeks:

	All of the time	Most of the time	A good bit of the time	Some of the time	A little of the time	None of the time
Have you felt calm and peaceful?	☐	☐	☐	☐	☐	☐
Did you have a lot of energy?	☐	☐	☐	☐	☐	☐
Have you felt downhearted and blue?	☐	☐	☐	☐	☐	☐

9.7 During the **past 4 weeks**, how much of the time has your **physical health or emotional problems** interfered with your social activities (like visiting friends, relatives etc). *Please tick one box only.*

All of the time ☐ Most of the time ☐ Some of the time ☐ A little of the time ☐ None of the time ☐

Thank you for your help with this research study

Please return this questionnaire in the pre-paid envelope provided. **You do not need a stamp.** Alternatively you may complete the questionnaire online at:

https://www.survey.bris.ac.uk/nottingham/olympians

If you have any questions about this questionnaire or the study in general, you can contact Dale Cooper on 0115 8231411 or by email at: msxdjc@exmail.nottingham.ac.uk

Section nine - about your general health

The next set of questions asks for **your views about your health**. Please tick one box for every question.

9.1 In general, would you say **your health** is:

☐ Excellent ☐ Very good ☐ Good ☐ Fair ☐ Poor

9.2 The following questions are about activities you may do during a typical day. **Does your health now limit you** in these activities?

	Yes, limited a lot	Yes, limited a little	No, not at all
Climbing **several** flights of stairs	☐	☐	☐
Moderate activities, such as moving a table, pushing a vacuum cleaner, bowling or playing golf	☐	☐	☐

9.3 During the **past 4 weeks**, have you had any of the following problems with work or other regular daily activities **as a result of your physical health?**

Accomplished less than you would like	Yes	☐	No	☐
Were **limited** in the **kind** of work or other activities	Yes	☐	No	☐

9.4 During the **past 4 weeks**, have you had any of the following problems with your work or other regular daily activities **as a result of any emotional problems** (e.g feeling depressed or anxious)?

Accomplished less than you would like	Yes	☐	No	☐
Did work or other activities **less carefully than usual**	Yes	☐	No	☐

1.9 Please indicate which of the following was the **main reason/s for retiring** from your athletic sports career:

	1st reason	*2nd reason (if applicable)*	*3rd reason (if applicable)*
Achieved all that was possible	☐	☐	☐
Decline in capability i.e. fitness	☐	☐	☐
Alternative career	☐	☐	☐
Injury – recurrent	☐	☐	☐
Injury - one off major injury	☐	☐	☐
Deselected	☐	☐	☐
Other reason *(please describe below)*	☐	☐	☐

.....

1.10 If you retired from your athletic sports career due to injury, please specify below the **location** and **nature of injury**:

Location (e.g. right knee): .....

Nature (e.g. ligament injury):.....

1.11 Please indicate **MAIN types of employment** (before, during and after your athletic sports career):

Job title (E.g. teacher)	Date from (mm / yr)	Date to (mm / yr)	Full time (FT)* Part time (PT)*
1	/	/	☐ FT ☐ PT
2	/	/	☐ FT ☐ PT
3	/	/	☐ FT ☐ PT
4	/	/	☐ FT ☐ PT
5	/	/	☐ FT ☐ PT
6	/	/	☐ FT ☐ PT
7	/	/	☐ FT ☐ PT

* **Full Time**: more than 20 hours per week; **Part Time**: 20 hours or less per week

Section two - your sports & activities

2.1 We would now like to ask you about the main sport/s or physical activities you participate(d) in at (i) school level (ii) club level (iii) national standard (iv) international standard (v) post international standard (vi) and any other (if you took part in more than one sport at the same level please list all events / sports separately). If you are still undertaking the sport/s or physical activities please put todays date in the appropriate box below (i.e. until mm/yr).

Level (I.e. School, Club, National, International, Post International, Other)	Sport	From *(mm/yr)*	Until *(mm/yr)*	Average hours of training per week	Average number of weeks training per year

2.2 We would like you to describe the **main types of training** you participate(d) in during your athletic sports career (please list each major training activity separately).

Activity / Training	From *(mm/yr)*	Until *(mm/yr)*	Type of surface you trained on	Average hours of training per week	Average number of weeks training per year

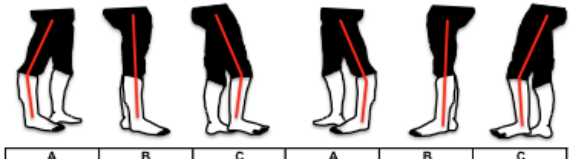
Section eight - your family

8.1 Please could you indicate using the boxes below whether **your immediate family** (mother, father, brother, sister, grandparents, children) have had joint replacement surgery.

Family member	Joint replacement surgery	Reason for surgery	Knobbly fingers (nodes - see page 10)
E.g. Father	Right hip	Fracture	Yes

8.2 Please record below if osteoarthritis, sometimes also referred to as joint degenerative disease, has been diagnosed by a physician in any member of **your immediate family** (parents, grandparents, brothers, sisters, children). Please indicate the family member/s and their affected joint/s.

Family Member	Affected joint e.g. right knee



A Right knee bent backwards	B Right knee straight	C Right knee bent forwards	A Left knee bent backwards	B Left knee straight	C Left knee bent forwards

7.10a Which picture above best shows how far you can bend your knee backwards (please score both knees)?

LEFT knee A ☐ B ☐ C ☐ RIGHT knee A ☐ B ☐ C ☐

7.10b Which picture above best shows how far you can bend your knee backwards in your 20s (please score both knees)?

LEFT knee A ☐ B ☐ C ☐ RIGHT knee A ☐ B ☐ C ☐

Section three - your health

3.1 Have you ever been diagnosed by your doctor as having any of the following **medical conditions**? *(Please tick all applicable boxes):*

- ☐ .... High blood pressure
- ☐ .... Heart attack
- ☐ .... Psoriatic arthritis
- ☐ .... Ankylosing spondylitis
- ☐ .... Another Inflammatory arthritis
- ☐ .... Diabetes
- ☐ .... Ehlers-Danlos syndrome
- ☐ .... Other, please specify.....
- ☐ .... Rheumatoid arthritis
- ☐ .... Osteoporosis
- ☐ .... Systemic lupus erythematosus
- ☐ .... Cancer
- ☐ .... Gout
- ☐ .... Marfan syndrome
- ☐ .... Osteogenesis imperfecta

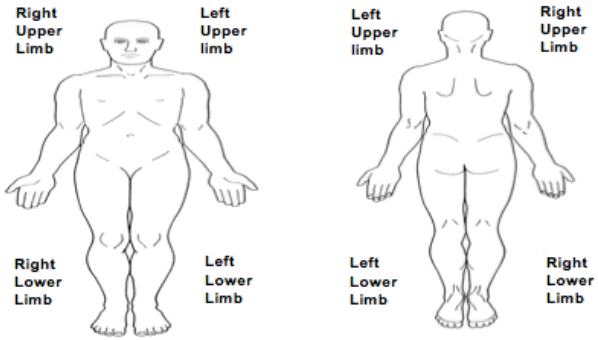
3.2 Are you currently taking any **medication** Yes ☐ No ☐ *(if no, please move to question 3.4)*

3.3 If you answered yes, do you take any of the following **medications**? *(Please tick all applicable boxes):*

- ☐ .... Etanercept
- ☐ .... Infliximab
- ☐ .... Methotrexate
- ☐ .... Inflammatory arthritis gold
- ☐ .... Eflunamid
- ☐ .... Plaquenil
- ☐ .... Other, please specify.....

3.4 We would now like you to consider **any recent pain you have experienced anywhere in your body**. By pain we mean pain, aching, discomfort and / or stiffness **that has lasted for most days of the previous month.** Please do not include pain due to feverish illness such as the flu. If you **have not** had any body pain that has lasted for most days of the previous month, please tick the box ☐ and **move to question 3.5**

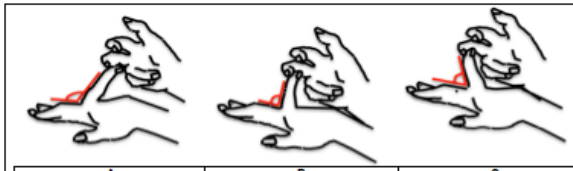
Please show where you have had pain by colouring in the body chart below.



3.5 We would now like you to consider **any recent pain you have experienced anywhere in your body** for most days for at least **three months**. Please show where you have had this type of pain by marking the body chart above with the letter P.

3.6 We are now interested in **the level of pain** you have experienced. By pain we are referring to **any type of pain**. Please exclude pain due to feverish illness such as the flu. **Please indicate the level of pain you have experienced in the past month** by marking the line below.

No pain _____ **Worst imaginable pain**



A	B	C
Index finger bends past 90 degrees	Index finger bends 90 degrees	Index finger bends less than 90 degrees

7.8a Which picture above best shows how far you can bend your index finger backwards (please score both hands)?

LEFT index finger A ☐ B ☐ C ☐ RIGHT index finger A ☐ B ☐ C ☐

7.8b Which picture above best shows how far you can bend your index finger backwards in your 20s (please score both hands)?

LEFT index finger A ☐ B ☐ C ☐ RIGHT index finger A ☐ B ☐ C ☐

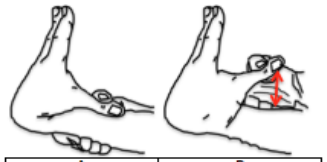
A	B	C
Elbow bent upwards	Elbow straight	Elbow bent backwards

7.9a Which picture above best shows how far you can bend your elbow backwards whilst keeping the palm of your hand facing upwards towards the ceiling (please score both elbows)?

LEFT elbow A ☐ B ☐ C ☐ RIGHT elbow A ☐ B ☐ C ☐

7.9b Which picture above best shows how far you can bend your elbow backwards whilst keeping the palm of your hand facing upwards towards the ceiling in your 20s (please score both elbows)?

LEFT elbow A ☐ B ☐ C ☐ RIGHT elbow A ☐ B ☐ C ☐



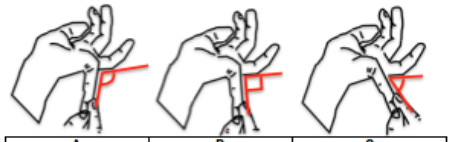
A Thumb touches forearm	B Thumb doesn't touch forearm

7.6a Which picture above best shows how far you can bend your **thumbs** to touch your wrist (please score both hands)?

LEFT thumb A ☐ B ☐ RIGHT thumb A ☐ B ☐

7.6b Which diagram above best shows how far you can bend your **thumbs** to touch your wrist in your 20s (please score both hands)?

LEFT thumb A ☐ B ☐ RIGHT thumb A ☐ B ☐



A Little finger bends past 90 degrees	B Little finger bends 90 degrees	C Little finger bends less than 90 degrees

7.7a Which picture above best shows how far you can bend your little finger backwards (please score both hands)?

LEFT little finger A ☐ B ☐ C ☐ RIGHT little finger A ☐ B ☐ C ☐

7.7b Which picture above best shows how far you can bend your little finger backwards in your 20s (please score both hands)?

LEFT little finger A ☐ B ☐ C ☐ RIGHT little finger A ☐ B ☐ C ☐

3.7 Have you previously had **surgery**? Yes ☐ No ☐ (If yes, please complete the table below)

Type of surgery (e.g. joint replacement)	Body area (e.g. right knee)	Your age when it occurred	Reason for surgery (e.g. arthritis / fracture)

Section four - your injuries

4.1 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?

Yes ☐ (If yes, please complete the table below).

No ☐

NB If you have sustained more than one significant injury to the same body part, please document each occurrence separately in the table below.

Body part	Age at time of injury	Type of injury	Sport / event you were involved in	If it occurred in competition, please describe the type of competition below	If occurred in training, please describe the type of training below
E.g. Right Shoulder	22	Fracture	Speed skating	World Championship	Plyometrics

Section seven - your joints

7.1 As a child did you amuse your friends by contorting your body into strange shapes or could you do the splits?

Yes ☐ No ☐

7.2 As a child or teenager did your shoulder or kneecap dislocate on more than one occasion?

Yes ☐ No ☐

7.3 Do you consider yourself double-jointed?

Yes ☐ No ☐

7.4 Have you ever been diagnosed with hypermobile joints **by a physician** (for example, your GP) or **any other health care provider** (for example, a physiotherapist)?

Yes ☐ No ☐

You will be presented with a series of pictures that relate to how flexible your joints are. We would like you to look at these pictures, and if it is safe for you to do so, we would like you to try and perform the same movement in front of a mirror. Your flexibility may differ between your right and left side so please score each limb separately where applicable. **Please also score your joints now**, and **if you are over 30**, please **score which picture best shows your joint angles in your 20s using your best estimate**.

A	B	C	D	E	F
Can't touch floor	Finger tips touching floor	Palms of hands on floor	Can't touch toes	Can touch toes	Can reach over toes

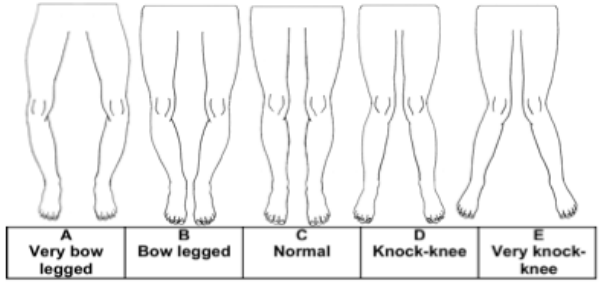
7.5 Which picture above (A, B, or C) best shows how far you can bend forwards without bending your knees? (If it is not safe for you to attempt this, how far forwards can you reach forwards in sitting (i.e. option D, E or F)?

	A	B	C	D	E	F
Now	☐	☐	☐	☐	☐	☐
In your 20s	☐	☐	☐	☐	☐	☐

Section six - your knees

We are interested in the **angle of your legs** (that is, straight legs, bow-legged or knock-knees) as this may have relevance to the development of osteoarthritis. Please look at your legs whilst standing (preferably in front of a mirror) and then indicate the angle of your legs based on the diagram below.

Most people will have similar angulations in their left and right knees, but in a few people these angulations may differ. We therefore would like you to score your knees separately.



6.1 Which picture best shows the **current** angle of **each** of your legs?

Right Knee ☐ A ☐ B ☐ C ☐ D ☐ E

Left Knee ☐ A ☐ B ☐ C ☐ D ☐ E

6.2 If you are over the age of 30, which picture do **you think** best shows the angle of **each** of your legs **in your 20s? If you are under 30, please go to the next question.**

Right Knee ☐ A ☐ B ☐ C ☐ D ☐ E

Left Knee ☐ A ☐ B ☐ C ☐ D ☐ E

6.3 Have you ever had **significant pain** in and around your knees for **most days for at least one month**?

Yes ☐ If yes, please indicate how old you were when you first noticed this type of pain in your:

Right Knee……years old

Left Knee……years old

No ☐

4.2 Have you ever been diagnosed with osteoarthritis in any of your joints **by a physician** (for example, your GP)?

Yes ☐ No ☐

4.3 Have you ever been diagnosed with osteoarthritis in any of your joints **by any other healthcare provider** (for example, a physiotherapist)?

Yes ☐ No ☐

If you have been **diagnosed with osteoarthritis**, please complete the table below.

Joint/s affected	Age at the time of diagnosis	Year you last experienced symptoms	Who diagnosed you	Investigation	Please specify type of treatment received
E.g. Right knee	25 years	Sept 2013	GP	X-ray	Physiotherapy – exercise

4.4 Have you received a **steroid injection** for pain?

Yes ☐ If yes, please indicate the number of steroid injections:……

If yes, how many of these did you have in order to compete or train:……

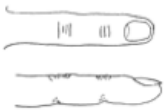
No ☐

Section five - your hands

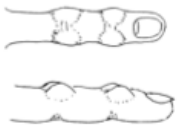
We are interested in knowing whether you have any **finger nodes**. These sometimes relate to arthritis at the hand and other joints. A finger **node** is a firm, bobbly swelling on the back of the finger joint.

For example:

A finger **without** nodes:



A finger **with** nodes:



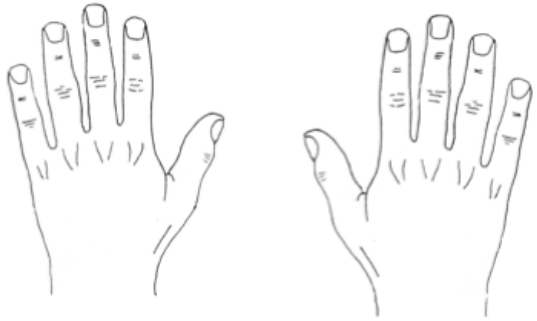
Please look at your hands and then answer the question below

5.1. Do you think you have any **nodes / swellings** on your hands?

Yes ☐ If yes, for each hand please circle on the diagram below the finger joint(s) where you have these nodes (You may circle several joints).

No ☐ (If no, please move to the next question).

LEFT **RIGHT**

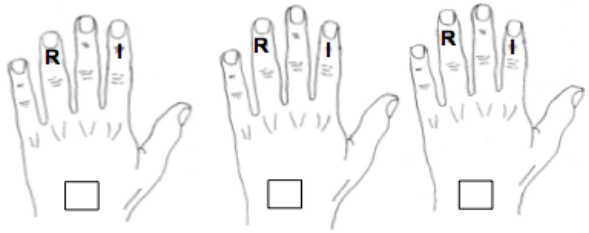


The 2D: 4D ratio is the ratio between the index and ring finger. The length of these two fingers has been associated with competitiveness, athleticism and more recently knee osteoarthritis.

Please look at **your left hand with your fingers straight in line with your forearm**. Ignore your middle finger and focus only on your left index (I) and ring (R) fingers.

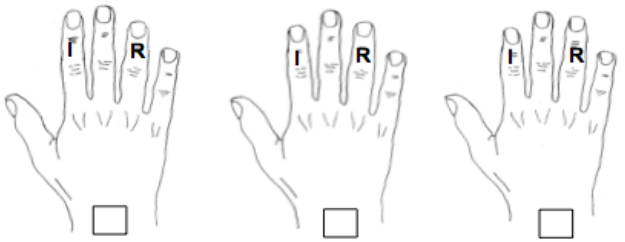
5.2 Please indicate which diagram **best shows the length of your left index finger in comparison to your left ring finger** *(please tick the appropriate box)*.

Index finger is longer than ring finger	Both fingers are equal	Ring finger is longer than index finger

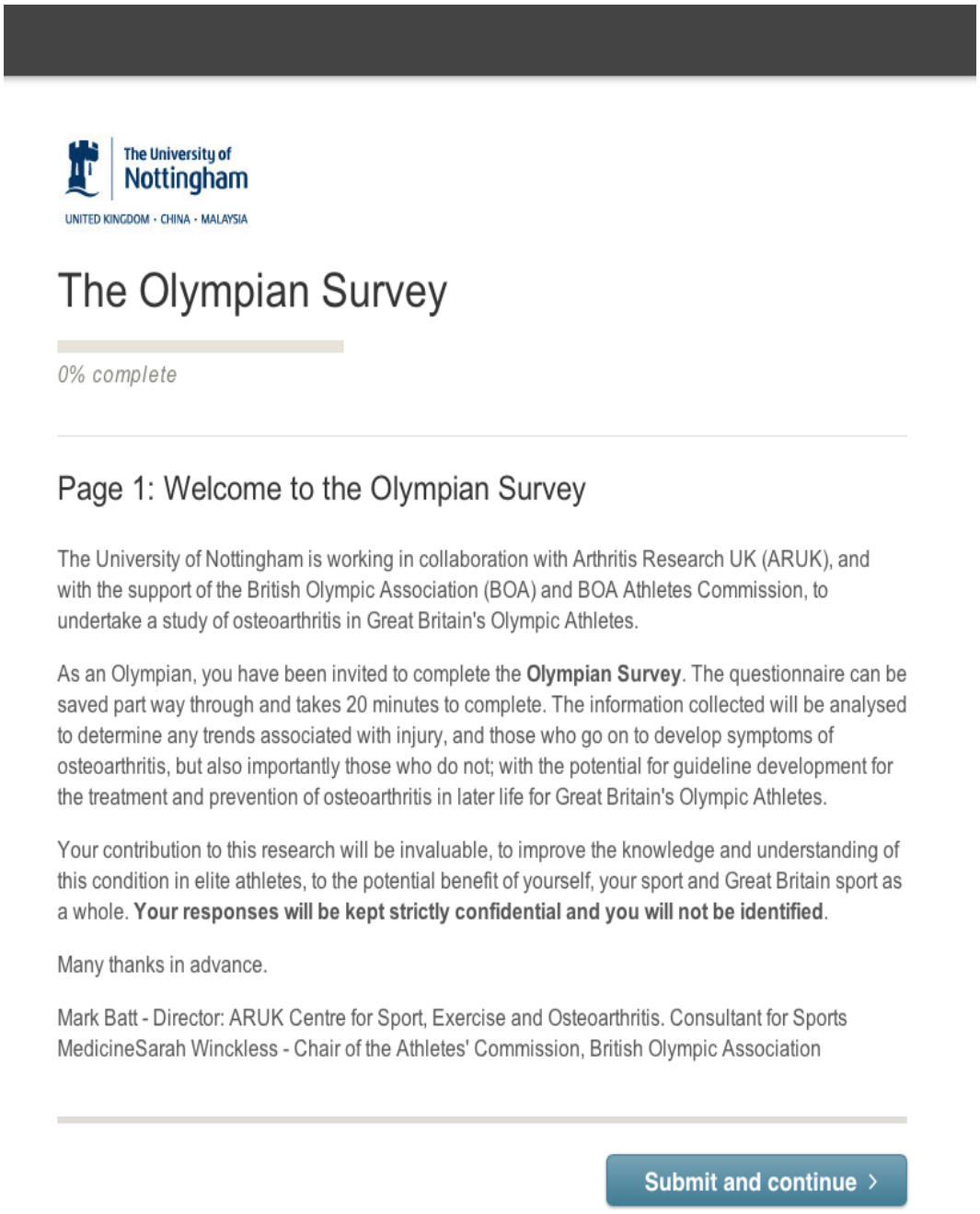


5.3 Now, do the same for your **right index and ring fingers** using the set of pictures below.

Index finger is longer than ring finger	Both fingers are equal	Ring finger is longer than index finger



APPENDIX H: Olympian Questionnaire: Web-Version



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The Olympian Survey

0% complete

Page 1: Welcome to the Olympian Survey

The University of Nottingham is working in collaboration with Arthritis Research UK (ARUK), and with the support of the British Olympic Association (BOA) and BOA Athletes Commission, to undertake a study of osteoarthritis in Great Britain's Olympic Athletes.

As an Olympian, you have been invited to complete the **Olympian Survey**. The questionnaire can be saved part way through and takes 20 minutes to complete. The information collected will be analysed to determine any trends associated with injury, and those who go on to develop symptoms of osteoarthritis, but also importantly those who do not; with the potential for guideline development for the treatment and prevention of osteoarthritis in later life for Great Britain's Olympic Athletes.

Your contribution to this research will be invaluable, to improve the knowledge and understanding of this condition in elite athletes, to the potential benefit of yourself, your sport and Great Britain sport as a whole. **Your responses will be kept strictly confidential and you will not be identified**.

Many thanks in advance.

Mark Batt - Director: ARUK Centre for Sport, Exercise and Osteoarthritis. Consultant for Sports MedicineSarah Winckless - Chair of the Athletes' Commission, British Olympic Association

Submit and continue ›

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The Olympian Survey

33% complete

Page 2: Data Protection

We intend to keep your details strictly confidential. For this reason we do not require you to give personal details such as your name, date of birth or address. You will be identified by a unique identification number. The master file that links your name and identification number will be password protected and held by the British Olympic Association. The research institution will only have access to your identification number.

Please note we take your confidentiality very seriously and have taken steps to protect your anonymity. Please read the participation information sheet for further details by clicking on the following link:http://www.sportsarthritisresearchuk.org/seoa/documents/olympics/participant-information-may.pdf

Please note that you will not be able to withdraw the information you have supplied after it has been submitted. The completion of the questionnaire is completely voluntary and should you choose to complete the questionnaire it implies you have consented to participate.

If you choose to complete the questionnaire, please complete it as accurately as possible, and please use your best estimate in situations where you are unsure. On completing the questionnaire you will have the choice to be entered into a free prize draw for two tickets to a sporting event to be confirmed.

Note that once you have clicked on the CONTINUE button at the bottom of each page you cannot return to review or amend that page

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The Olympian Survey

66% complete

Page 3

Questions are **mandatory** unless marked otherwise.

Note that once you have clicked on the **CONTINUE** button your answers are submitted and you can not return to review or amend that page.

Section 1 - About you

1 Would you like to be entered into a **free prize draw** (on completing the questionnaire) to win two tickets for a sporting event to be confirmed?

- ◯ Yes
- ◯ No

2 Please enter your **identification number** (located on the sticky label at the top of the invitation letter or in the label field if you received an invitation by email):

More info

3 What is your **gender**?

◯ Male ◯ Female

4 Please select the **year** in which you were born:

Please select

5 Please select your **height** in feet and inches or alternatively in centimetres:

Having trouble with the format of this question? View in tableless mode

	In feet	and inches	Or centimetres
What is your height? (without shoes)	Please select	Please select	Please select

6 Please select your **current weight** in stone and pounds or alternatively in kilograms:

Having trouble with the format of this question? View in tableless mode

	In stones	and pounds	Or kilograms
What is your weight? (light clothing only)	Please select	Please select	Please select

7 How much did you **weigh in your 20s**? *(If you are currently in your 20s please move to the next question)*

Having trouble with the format of this question? View in tableless mode

	In stones	and stones	Or kilograms
How much did you **weigh in your 20s**?	Please select	Please select	Please select

8 Which **ethnic** group best describes you?

Please select

a If you selected **other**, please specify:

9 Which is your **dominant limb/s** for participating in your athletic sports career:

Having trouble with the format of this question? View in tableless mode

	Right	Left	Equally proficient
Upper limb (arm / hand)	○	○	○
Lower limb (leg / foot)	○	○	○

10 Are you **retired** from your athletic sports career?

○ Yes ○ No (if no, please go to question 13)

11 Please indicate which of the following was the **main reason/s for retiring** from your athletic sports career?

Having trouble with the format of this question? View in tableless mode

	Achieved all that was possible	Decline in capability i.e. fitness	Alternative career	Injury - recurrent	Injury - one off major injury	Deselected	Other reason	If you answered yes to **other reason**, please describe
1st reason	○	○	○	○	○	○	○	
2nd reason (if applicable)	○	○	○	○	○	○	○	
3rd reason (if applicable)	○	○	○	○	○	○	○	

12 If you retired from your athletic sports career due to injury, please select the **location of injury**:

Please select

a If you retired from your athletic sports career due to injury, please select the **nature of injury**:

Please select

b If you selected **other type of injury**, please describe below:

13 Please indicate your **MAIN types of employment** (before, during and after your athletic sports career) e.g. teacher:

Having trouble with the format of this question? View in tableless mode

	Job title	Date from	Date to	Hours per week	
				Part time (20 hours or less per week)	Full time (more than 20 hours per week)
Occupation (most recent first)		(dd/mm/yyyy)	(dd/mm/yyyy)	○	○
Occupation		(dd/mm/yyyy)	(dd/mm/yyyy)	○	○
Occupation		(dd/mm/yyyy)	(dd/mm/yyyy)	○	○
Occupation		(dd/mm/yyyy)	(dd/mm/yyyy)	○	○
Occupation		(dd/mm/yyyy)	(dd/mm/yyyy)	○	○
Occupation		(dd/mm/yyyy)	(dd/mm/yyyy)	○	○

Section 2: Your sports and activities

14 We would now like to ask you about the main **sport/s or physical activities** you participate(d) in at (i) school level (ii) club level (ii) national standard (iii) international standard (iv) post international standard (v) and any other (if you took part in more than one sport at the same level please list all events / sports sperately. If you are still undertaking the sport/s or physical activities please select the current date in the appropriate box (i.e. until).

Having trouble with the format of this question? View in tableless mode

	Level	Sport	From	Until	Average hours of training per week	Average number of weeks training per year
Sports	Please select		(dd/mm/yyyy)	(dd/mm/yyyy)	Please select	Please select
Sports	Please select		(dd/mm/yyyy)	(dd/mm/yyyy)	Please select	Please select
Sports	Please select		(dd/mm/yyyy)	(dd/mm/yyyy)	Please select	Please select
Sports	Please select		(dd/mm/yyyy)	(dd/mm/yyyy)	Please select	Please select
Sports	Please select		(dd/mm/yyyy)	(dd/mm/yyyy)	Please select	Please select
Sports	Please select		(dd/mm/yyyy)	(dd/mm/yyyy)	Please select	Please select

15 We would like you to describe the **main types of training** you participate(d) in during your athletic sports career (please list each major training activity separately):

Having trouble with the format of this question? View in tableless mode

	Activity / Training	From	Until	Surface	Average hours of training per week	Average number of weeks training per year
Training e.g. swimming		(dd/mm/yyyy)	(dd/mm/yyyy)	Please select	Please select	Please select
Training e.g weights		(dd/mm/yyyy)	(dd/mm/yyyy)	Please select	Please select	Please select
Training		(dd/mm/yyyy)	(dd/mm/yyyy)	Please select	Please select	Please select
Training		(dd/mm/yyyy)	(dd/mm/yyyy)	Please select	Please select	Please select
Training		(dd/mm/yyyy)	(dd/mm/yyyy)	Please select	Please select	Please select
Training		(dd/mm/yyyy)	(dd/mm/yyyy)	Please select	Please select	Please select
Training		(dd/mm/yyyy)	(dd/mm/yyyy)	Please select	Please select	Please select
Training		(dd/mm/yyyy)	(dd/mm/yyyy)	Please select	Please select	Please select
Training		(dd/mm/yyyy)	(dd/mm/yyyy)	Please select	Please select	Please select

Section 3: Your health

16 Have you ever been diagnosed by your doctor as having any of the following **medical conditions**?

- ☐ High blood pressure
- ☐ Heart attack
- ☐ Psoriatic arthritis
- ☐ Ankylosing spondylitis
- ☐ Another inflammatory arthritis
- ☐ Diabetes
- ☐ Ehlers-Danlos syndrome
- ☐ Rheumatoid arthritis
- ☐ Osteoporosis
- ☐ Systemic lupus erythematosus
- ☐ Cancer
- ☐ Gout
- ☐ Marfan syndrome
- ☐ Osteogenesis imperfecta
- ☐ Other medical condition

a If you selected **other medical condition**, would you please specify below:

17 Are you currently taking any **medication**?

- ○ Yes
- ○ No

a If you answered yes, do you take any of the following **medications**?

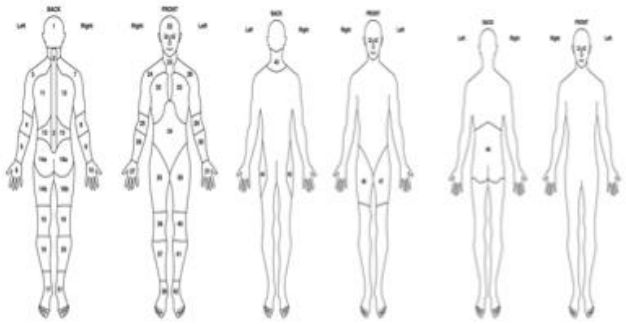
- ○ Etanercept
- ○ Inflammatory arthritis gold
- ○ Infliximab
- ○ Eflunamide
- ○ Methotrexate
- ○ Plaquenil
- ○ Other medication

b If you answered yes to **other medication**, would you please list the medications you are taking below:

18 We would now like you to consider **any recent pain you have experienced anywhere in your body**. By pain we mean pain, aching, discomfort and / or stiffness **that has lasted for most days of the previous month** or **most days for at least three months**. Please do not include pain due to illness such as the flu. Please select the body part, location, and give a brief description of where the symptoms are, for example, pain on the front and outside of my right thigh.

Having trouble with the format of this question? View in tableless mode

	Duration of symptoms	Body part	Location	Please describe where the symptoms are:
i	Please select	Please select	Please select	
ii	Please select	Please select	Please select	
iii	Please select	Please select	Please select	
iv	Please select	Please select	Please select	
v	Please select	Please select	Please select	



19 We are now interested in **the level of pain** you have experienced. By pain we are referring to **any type of pain**. Please exclude pain due to feverish illness such as the flu. **Please indicate the level of pain you have experienced in the past month** by selecting a number from the scale below (0 = no pain; 10 = worst imaginable pain).

- ○ 0 (no pain)
- ○ 1
- ○ 2
- ○ 3
- ○ 4
- ○ 5
- ○ 6
- ○ 7
- ○ 8
- ○ 9
- ○ 10 (worst imaginable pain)

20 Have you previously had **surgery**?

○ Yes ○ No (if no, please go to question 22)

21 If you've had **previous surgery**, please describe the procedure below:

Having trouble with the format of this question? View in tableless mode

	Type of surgery (e.g. joint replacement)	Body area	Your age when it occurred	Reason for surgery (e.g. arthritis / fracture)
Procedure		Please select	Please select	
Procedure		Please select	Please select	
Procedure		Please select	Please select	
Procedure		Please select	Please select	
Procedure		Please select	Please select	
Procedure		Please select	Please select	

Section 4: About your injuries

22 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?

○ Yes ○ No (if no, please go to question 24)

23 If you've sustained a **significant injury**, please describe below. NB If you sustained more than one significant injury to the same body part, please document each occurrence separately in the table below.

Having trouble with the format of this question? View in tableless mode

	Body part	Age at time of injury	Type of injury	Sport / event you were involved in	If it occurred in competition please complete below	If it occurred in training please complete below
Significant injury	Please select	Please select	Please select		Please select	Please select
Significant injury	Please select	Please select	Please select		Please select	Please select
Significant injury	Please select	Please select	Please select		Please select	Please select
Significant injury	Please select	Please select	Please select		Please select	Please select
Significant injury	Please select	Please select	Please select		Please select	Please select
Significant injury	Please select	Please select	Please select		Please select	Please select
Significant injury	Please select	Please select	Please select		Please select	Please select

24 Have you ever been diagnosed with osteoarthritis in any of your joints **by a physician** (for example, your GP)?

- ○ Yes
- ○ No

25 Have you ever been diagnosed with osteoarthritis in any of your joints **by any other healthcare provider** (for example, a physiotherapist)?

- ○ Yes
- ○ No

26 If you have been **diagnosed with osteoarthritis**, please complete the table below:

Having trouble with the format of this question? View in tableless mode

	Joint/s affected	Age at the time of diagnosis	Year you last experienced symptoms	Who diagnosed you?	What investigations have you had? (Please tick all applicable boxes)								Please specify the type of treatment received (e.g. physiotherapy - exercise)
					Ultrasound	X-ray	CT scan	MRI scan	Blood test	Keyhole surgery	Specialist	Other	
i	Please select	Please select	(dd/mm/yyyy)	Please select	☐	☐	☐	☐	☐	☐	☐	☐	
ii	Please select	Please select	(dd/mm/yyyy)	Please select	☐	☐	☐	☐	☐	☐	☐	☐	
iii	Please select	Please select	(dd/mm/yyyy)	Please select	☐	☐	☐	☐	☐	☐	☐	☐	
iv	Please select	Please select	(dd/mm/yyyy)	Please select	☐	☐	☐	☐	☐	☐	☐	☐	
v	Please select	Please select	(dd/mm/yyyy)	Please select	☐	☐	☐	☐	☐	☐	☐	☐	
vi	Please select	Please select	(dd/mm/yyyy)	Please select	☐	☐	☐	☐	☐	☐	☐	☐	

27 If you have received a **steroid injection** for pain, please complete the table below:

Having trouble with the format of this question? View in tableless mode

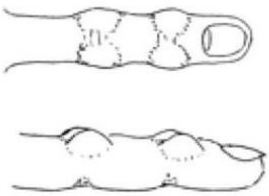
	Body part (location of injection)	Total number of steroid injections	Number of steroid injections to compete or train
i	Please select	Please select	Please select
ii	Please select	Please select	Please select
iii	Please select	Please select	Please select

Section 5 - About your hands

We are interested in knowing whether you have any **finger nodes**. These sometimes relate to arthritis at the hand and other joints. A finger **node** is a firm, knobbly swelling on the back of the finger joint.

For example: A finger **without** nodes:

A finger **with** nodes:

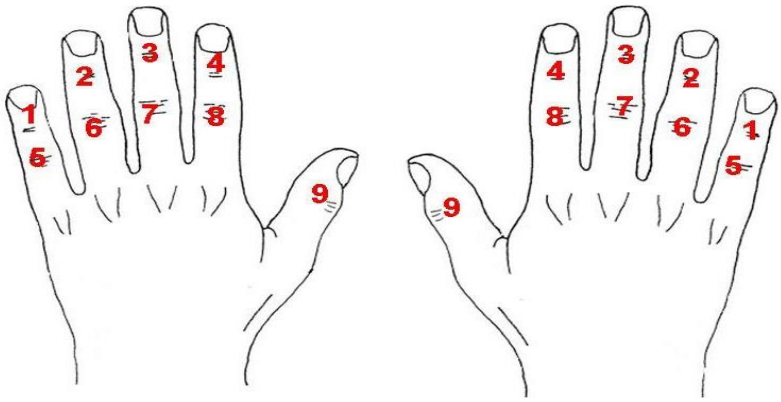


28 Do you think you have any **nodes/swellings** on your hands?

- ◯ Yes
- ◯ No

29 Please select the joints affected with nodes on your **left hand** using the numbers in the picture below:

☐ 1	☐ 2	☐ 3
☐ 4	☐ 5	☐ 6
☐ 7	☐ 8	☐ 9



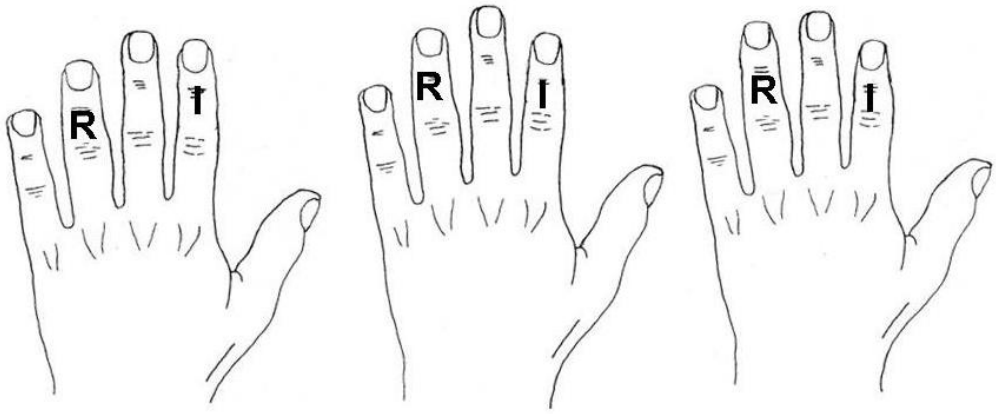
30 Please select the joints affected with nodes on your **right hand** using the numbers in the picture above:

☐ 1	☐ 2	☐ 3
☐ 4	☐ 5	☐ 6
☐ 7	☐ 8	☐ 9

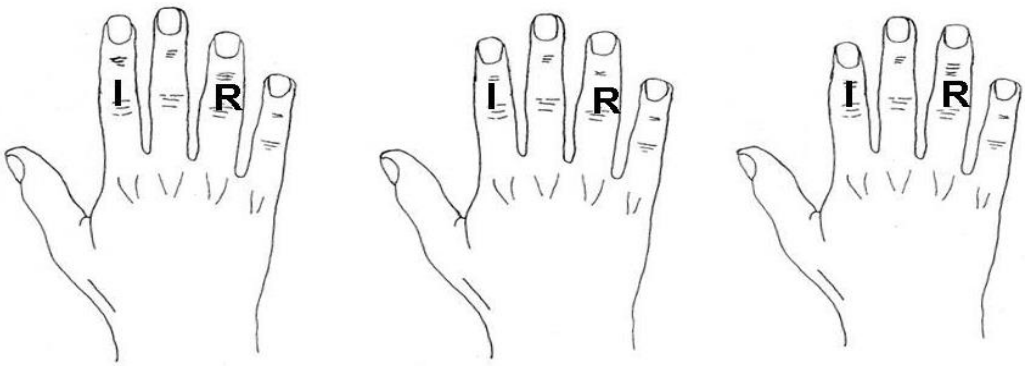
31 The 2D: 4D ratio is the ratio between the index and ring finger. The length of these two fingers has been associated with competitiveness, athleticism and more recently knee osteoarthritis. Please look at **your left hand with your fingers straight in line with your forearm**. Ignore your middle finger and focus only on your left index (I) and ring (R) fingers. Please indicate which diagram below **best shows the length of your index finger in comparison to your ring finger**.

Having trouble with the format of this question? View in tableless mode

	Finger patterning
Left hand	Please select
Right hand	Please select



A	B	C
Index finger is longer than ring finger	Both fingers are equal	Ring finger is longer than index finger



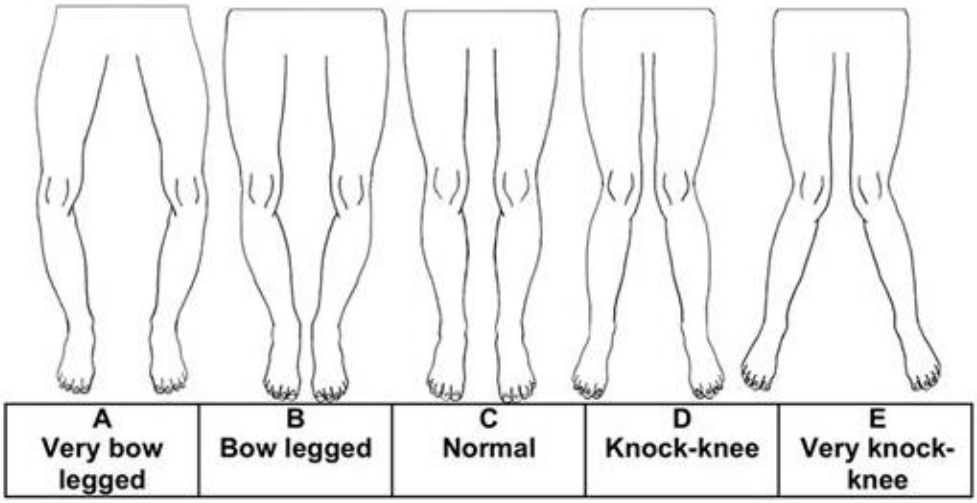
A Index finger is longer than ring finger	B Both fingers are equal	C Ring finger is longer than index finger

Section 6 - About your knees

32 We are interested in the **angle of your legs** (that is, straight legs, bow-legged or knock-knees) as this may have relevance to the development of osteoarthritis. Please look at your legs whilst standing (preferably in front of a mirror) and then indicate the angle of your legs based on the diagram below. Most people will have similar angulations in their left and right knees, but in a few people these angulations may differ. We therefore would like you to score your knees separately. If you are over the age of 30, please also indicate which diagram **you think** best shows the angle of **each** of your legs **in your 20s** (If you are not over the age of 30, please select n/a on the drop down menu).

Having trouble with the format of this question? View in tableless mode

	Angle of your legs now	Angle of your legs in your 20s
Which diagram best shows the angle of your **right knee**	Please select	Please select
Which diagram best shows the angle of your **left knee**	Please select	Please select



33 Have you ever had **significant pain** in and around your knees for **most days for at least one month**?

○ Yes ○ No (if no, please go to question 34)

a If yes, please indicate how old you were when you first noticed this type of pain in your **right knee** *(if applicable)*:

Please select

i If yes, please indicate how old you were when you first noticed this type of pain in your **left knee** *(if applicable)*:

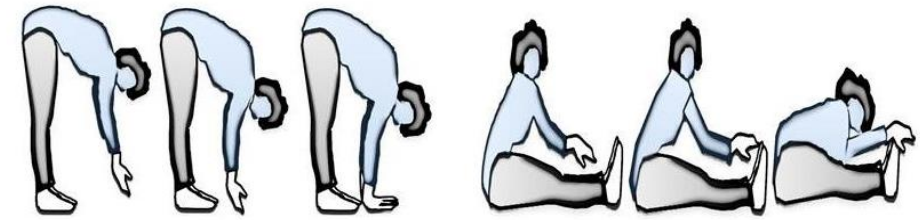
Please select

Section 7 - About your joints

You will be presented with a series of pictures that relate to how flexible your joints are. We would like you to look at these pictures, and if it is safe for you to do so, we would like you to try and perform the same movement in front of a mirror. Your flexibility may differ between your right and left side so please score each limb separately where applicable. **Please also score your joints now**, and **if you are over 30**, please **score which picture best shows your joint angles in your 20s using your best estimate**.

34 Which picture below (A, B, or C) best shows how far you can bend forwards without bending your knees? (if it is not safe for you to attempt this, how far forwards can you reach forwards in sitting i.e. option D, E or F)?

- ○ A Can't touch floor
- ○ B Finger tips touching floor
- ○ C Palms of hands on floor
- ○ D Can't touch toes (in sitting)
- ○ E Can touch toes only (in sitting)
- ○ F Can reach over toes (in sitting)



A	B	C	D	E	F
Can't touch floor	Finger tips touching floor	Palms of hands on floor	Can't touch toes	Can touch toes	Can reach over toes

a If you are over the age of 30, which picture above do **you think** best shows how far you could bend forwards without bending your knees **in your 20s**? **If you are under 30, please tick N/a and move to the next question**:

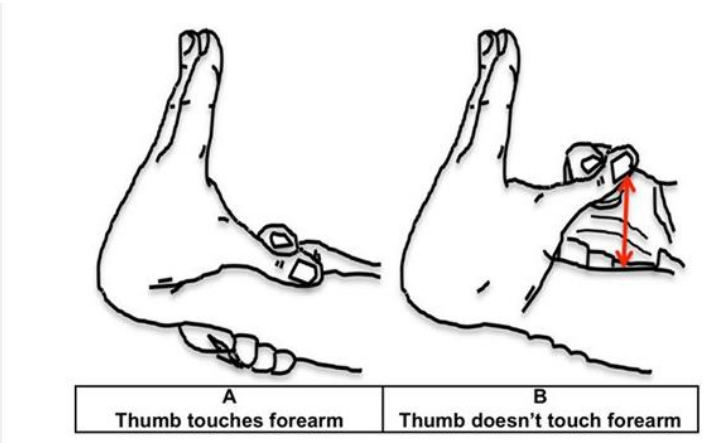
- ○ A Can't touch floor
- ○ B Finger tips touching floor
- ○ C Palms of hands on floor
- ○ D Can't touch toes (in sitting)
- ○ E Can touch toes only (in sitting)
- ○ F Can reach over toes (in sitting)
- ○ G N/a

35 Which picture below best shows how far you can bend your **LEFT thumb** to touch your wrist?

- ○ A Thumb touches forearm
- ○ B Thumb doesn't touch forearm

a If you are over the age of 30, which picture below do you think best shows how far you could bend your **LEFT thumb** to touch your forearm **in your 20s**? **If you are under 30, please tick N/a and move to the next question**:

- ○ A Thumb touches forearm
- ○ B Thumb doesn't touch forearm
- ○ C N/a



b Which picture above best shows how far you can bend your **RIGHT thumb** to touch your wrist?

- ○ A Thumb touches forearm
- ○ B Thumb doesn't touch forearm

i If you are over the age of 30, which picture above do you think best shows how far you could bend your **RIGHT thumb** to touch your forearm **in your 20s**? **If you are under 30, please tick N/a and move to the next question**:

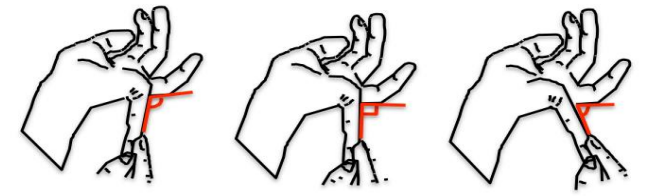
- A Thumb touches forearm
- B Thumb doesn't touch forearm
- C N/a

36 Which picture below best shows how far you can bend your **LEFT little finger** backwards?

- A Little finger bends past 90 degrees
- B Little finger bends 90 degrees
- C Little finger bends less than 90 degrees

a If you are over the age of 30, which picture below do you think best shows how far you could bend your **LEFT little finger in your 20s**? **If you are under 30, please tick N/a and move to the next question**:

- A Little finger bends past 90 degrees
- B Little finger bends 90 degrees
- C Little finger bends less than 90 degrees
- D N/a



A	B	C
Little finger bends past 90 degrees	**Little finger bends 90 degrees**	**Little finger bends less than 90 degrees**

b Which picture above best shows how far you can bend your **RIGHT little finger** backwards?

- A Little finger bends past 90 degrees
- B Little finger bends 90 degrees
- C Little finger bends less than 90 degrees

i If you are over the age of 30, which picture above do you think best shows how far you could bend your **RIGHT little finger in your 20s**? **If you are under 30, please tick N/a and move to the next question**:

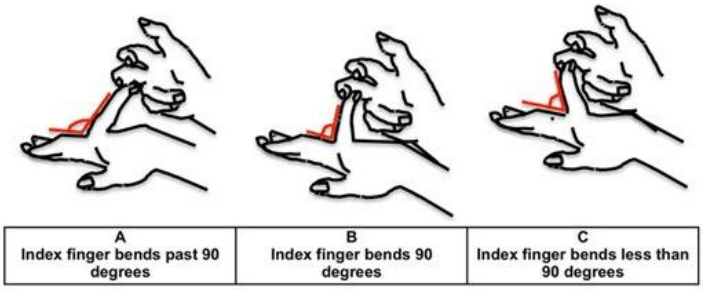
- ○ A Little finger bends past 90 degrees
- ○ B Little finger bends 90 degrees
- ○ C Little finger bends less than 90 degrees
- ○ D N/a

37 Which picture below best shows how far you can bend your **LEFT index finger** backwards?

- ○ A Index finger bends past 90 degrees
- ○ B Index finger bends 90 degrees
- ○ C Index finger bends less than 90 degrees

a If you are over the age of 30, which picture below do you think best shows how far you could bend your **LEFT index finger in your 20s? If you are under 30, please tick N/a and move to the next question**:

- ○ A Index finger bends past 90 degrees
- ○ B Index finger bends 90 degrees
- ○ C Index finger bends less than 90 degrees
- ○ D N/a



A Index finger bends past 90 degrees	B Index finger bends 90 degrees	C Index finger bends less than 90 degrees

b Which picture above best shows how far you can bend your **RIGHT index finger** backwards?

- ○ A Index finger bends past 90 degrees
- ○ B Index finger bends 90 degrees
- ○ C Index finger bends less than 90 degrees

i If you are over the age of 30, which picture above do you think best shows how far you could bend your **RIGHT index finger in your 20s? If you are under 30, please tick N/a and move to the next question**:

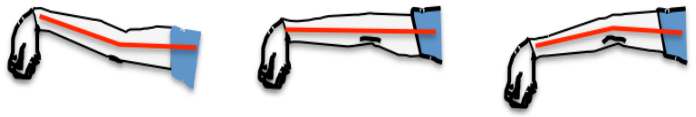
- A Index finger bends past 90 degrees
- B Index finger bends 90 degrees
- C Index finger bends less than 90 degrees
- D N/a

38 Which picture below best shows how far you can bend your **LEFT elbow** backwards whilst keeping the palm of you hand facing upwards towards the ceiling??

- A Elbow bent upwards
- B Elbow straight
- C Elbow bent backwards

a If you are over the age of 30, which picture below do you think best shows how far you could bend your **LEFT elbow** backwards **in your 20s**? **If you are under 30, please tick N/a and move to the next question**:

- A Elbow bent upwards
- B Elbow straight
- C Elbow bent backwards
- D N/a



A Elbow bent upwards	B Elbow straight	C Elbow bent backwards

i Which picture above best shows how far you can bend your **RIGHT elbow** backwards whilst keeping the palm of you hand facing upwards towards the ceiling?

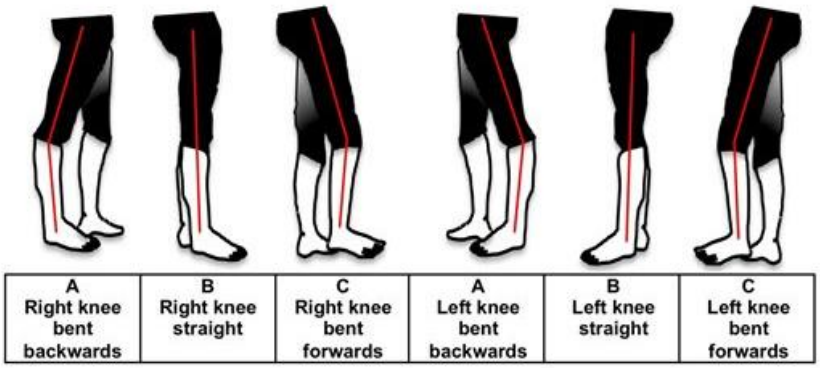
- A Elbow bent upwards
- B Elbow straight
- C Elbow bent backwards

ii If you are over the age of 30, which picture above do you think best shows how far you could bend your **RIGHT elbow** backwards **in your 20s**? **If you are under 30, please tick N/a and move to the next question**:

- A Elbow bent upwards
- B Elbow straight
- C Elbow bent backwards
- D N/a

39 Which picture below best shows how far you can bend your **LEFT knee** backwards?

- ○ A Left knee bent backwards
- ○ B Left knee straight
- ○ C Left knee bent forwards



a If you are over the age of 30, which picture below do you think best shows how far you could bend your **LEFT knee** backwards **in your 20s**? **If you are under 30, please tick N/a and move to the next question**:

- ○ A Left knee bent backwards
- ○ B Left knee straight
- ○ C Left knee bent forwards
- ○ D N/a

b Which picture above best shows how far you can bend your **RIGHT knee** backwards?

- ○ A Right knee bent backwards
- ○ B Right knee straight
- ○ C Right knee bent forwards

i If you are over the age of 30, which picture above do you think best shows how far you could bend your **RIGHT knee** backwards **in your 20s**? **If you are under 30, please tick N/a and move to the next question**:

- ○ A Right knee bent backwards
- ○ B Right knee straight
- ○ C Right knee bent forwards
- ○ D N/a

40 As a child did you amuse your friends by contorting your body into strange shapes or could you do the splits?

- ◯ Yes
- ◯ No

41 As a child or teenager did your shoulder or kneecap dislocate on more than one occasion?

- ◯ Yes
- ◯ No

42 Do you consider yourself double-jointed?

- ◯ Yes
- ◯ No

43 Have you ever been diagnosed with hypermobile joints **by a physician** (for example, your GP) or **any other health care provider** (for example, a physiotherapist)?

- ◯ Yes
- ◯ No

Section 8 - About your family

44 Please could you indicate using the table below whether **your immediate family** (mother, father, brother, sister, grandparents, children) have had joint replacement surgery.

Having trouble with the format of this question? View in tableless mode

	Family member	Joint replacement surgery	Reason for surgery	Knobbly fingers (nodes)
Family member	Please select	Please select	Please select	Please select
Family member	Please select	Please select	Please select	Please select
Family member	Please select	Please select	Please select	Please select
Family member	Please select	Please select	Please select	Please select
Family member	Please select	Please select	Please select	Please select
Family member	Please select	Please select	Please select	Please select
Family member	Please select	Please select	Please select	Please select
Family member	Please select	Please select	Please select	Please select

45 Please record below if osteoarthritis, sometimes also referred to as joint degenerative disease, has been diagnosed by a physician in any member of **your immediate family** (parents, grandparents, brothers, sisters, children). Please indicate the family member/s and their affected joints.

Having trouble with the format of this question? View in tableless mode

	Family member	Affected joint
Family member	Please select	Please select
Family member	Please select	Please select
Family member	Please select	Please select
Family member	Please select	Please select
Family member	Please select	Please select
Family member	Please select	Please select
Family member	Please select	Please select
Family member	Please select	Please select
Family member	Please select	Please select

Section 9 - About your general health

The next set of questions asks for **your views about your health**. Please tick one box for every question.

46 In general, would you say **your health** is:

- ○ Excellent
- ○ Very good
- ○ Good
- ○ Fair
- ○ Poor

47 The following questions are about your activities you may do during a typical day. **Does your health now limit you** in these activities?

Having trouble with the format of this question? View in tableless mode

	Yes, limited a lot	Yes, limited a little	No, not at all
Climbing **several** flights of stairs:	○	○	○
Moderate activities, such as moving a table, pushing a vacuum cleaner, bowling or playing golf:	○	○	○

48 During the **past 4 weeks**, have you had any of the following problems with work or other regular daily activities **as a result of your physical health?**

Having trouble with the format of this question? View in tableless mode

	Yes	No
Accomplished less than you would like:	○	○
Were **limited** in the **kind** of work or other activities:	○	○

49 During the **past 4 weeks**, have you had any of the following problems with your work or other regular activities **as a result of any emotional problems** (e.g. feeling depressed or anxious)?

Having trouble with the format of this question? View in tableless mode

	Yes	No
Accomplished less than you would like:	○	○
Did work or other activities **less carefully than usual**:	○	○

50 During the **past 4 weeks** how much did **pain** interfere with your normal work (including both work outside the home and housework)?

- ○ Not at all
- ○ A little bit
- ○ Moderately
- ○ Quite a bit
- ○ Extremely

51 These next questions are about how you feel and how things have been with you **during the past 4 weeks**. For each question, please give the one answer that is closest to the way you have been feeling. How much of the time during the past 4 weeks -

Having trouble with the format of this question? View in tableless mode

	All of the time	Most of the time	A good bit of the time	Some of the time	A little of the time	None of the time
Have you felt calm and peaceful?	○	○	○	○	○	○
Did you have a lot of energy?	○	○	○	○	○	○
Have you felt downhearted and blue?	○	○	○	○	○	○

52 During the **past 4 weeks**, how much of the time has your **physical health or emotional problems** interfered with your social activities (like visiting friends, relatives etc). *(Please tick one box only)*

- ○ All of the time
- ○ Most of the time
- ○ Some of the time
- ○ A little of the time
- ○ None of the time

Finish ✓

The Olympian Survey

100% complete

Thank you for taking the time to complete this questionnaire. If you have any questions about this questionnaire or the study in general, you can contact Dale Cooper on 0115 8231411 or by email at msxdjc@exmail.nottingham.ac.uk

If you wish to support the centres work further you can find out more at: http://www.sportsarthritisresearchuk.org

Thank you for participating in this study.

Mark Batt - Director: ARUK Centre for Sport, Exercise and Osteoarthritis. Consultant for Sports MedicineSarah Winckless - Chair of the Athletes' Commission, British Olympic Association

APPENDIX I: Coding Menus for the Web-Based Olympian

Questionnaire

Question 5

Height in feet. Scale of 4 to 7 feet in 1 foot increments	Height in inches. Scale of 0 to 11 inches in 1-inch increments.	100 to 240 Centimetres in 1 Centimetre increments

Question 6 and 7

Weight in stone. Scale of 4 to 30+ stones in 1 stone increment's.	Weight in pounds. Scale of 0 to 13 pounds in 1 pounds increments.	25 to 220 Kilograms in 1 Kilogram increments

Question 8

White (English, Welsh, Scottish, British, Northern Irish)	Mixed (White & Asian)
Black African	Mixed (White & Black Caribbean)
Black British	Asian / Asian British (Indian, Pakistani, Bangladeshi, Chinese)
Black Caribbean	Other
Mixed (White & Black African)	

Question 9 and 10

Right hand	Left hand	Equally proficient

Question 12

Head	Right Upper Arm	Right Hip
Neck	Left Upper Arm	Left Hip
Upper Back	Right Lower Arm	Right Upper Leg
Lower Back	Left Lower Arm	Left Upper Leg
Right shoulder	Right Wrist	Right Knee
Left Shoulder	Left Wrist	Left Knee
Right Elbow	Right Hands/Fingers	Right Lower Left
Left Elbow	Left Hands/Fingers	Left Lower Leg

Question 12 a

Concussion	Injury of joint	Tendon injury
Fracture	Cartilage injury	Arthritis
Stress fracture	Muscle injury	Laceration
Dislocation	Ligament injury	Other

Question 14

School	Club	National Standard
International Standard	Post International Standard	Other

Question 14

Mean hours of training per week 1-40+	Mean number of weeks training per year 1-50+

Question 15

Clay	Grass	Gymnasium	Ice
Road	Snow	Track	Trail
Water	Other		

Question 15

Mean hours of training per week 1-40+	Mean number of weeks training per year 1-50+

Question 18

Pain lasting for most days of the previous month	Pain lasting for most days for last 3 months

Question 18

Coded 1 to 48 on body manikin

Question 18

Front	Back

Question 21

Head	Right Upper Arm	Right Hip
Neck	Left Upper Arm	Left Hip
Upper Back	Right Lower Arm	Right Upper Leg
Lower Back	Left Lower Arm	Left Upper Leg
Right shoulder	Right Wrist	Right Knee
Left Shoulder	Left Wrist	Left Knee
Right Elbow	Right Hands/Fingers	Right Lower Left
Left Elbow	Left Hands/Fingers	Left Lower Leg

Question 21

Your age when it occurred 1 - 90+

Question 23

Head	Right Upper Arm	Right Upper Leg
Face	Left Upper Arm	Left Upper Leg
Neck	Right Lower Arm	Right Knee
Upper / Middle Back	Left Lower Arm	Left Knee
Lower Back	Right Wrist	Right Lower Left
Chest	Left Wrist	Left Lower Leg
Abdomen	Right Fingers	Right Ankle
Pelvis	Left Fingers	Left Ankle
Right shoulder	Right Hip	Right Toes
Left Shoulder	Left Hip	Left Toes
Right Elbow	Right Groin	Other (please describe)
Left Elbow	Left Groin	

Question 23

Your age when it occurred 1 - 90+

Question 23

Concussion	Injury of joint	Tendon injury
Fracture	Cartilage injury	Arthritis
Stress fracture	Muscle injury	Laceration
Dislocation	Ligament injury	Other

Question 23

Olympic Games	World Cup	National Championship
Paralympic Games	European Championship	Domestic trials
World Cup Championships	International - other	Domestic other

Question 23

Agility drills	Prehab
Circuits	Running
Conditioning	Rowing
Core Gym	Sport specific
Pilates	Swimming
Plyometrics	Weights

Question 26

Neck	Right Elbow	Left Thumb	Right Toes
Jaw	Left Elbow	Right Hip	Left Toes
Upper / Middle Back	Right Wrist	Left Hip	Right Big Toe
Right Shoulder	Left Wrist	Right Knee	Left Big Toe
Left Shoulder	Right Fingers	Left Knee	Other
Right Collarbone	Left Fingers	Right Ankle	
Left Collarbone	Right Thumb	Left Ankle	

Question 26

Age at the time of diagnosis 0 – 90+ years

Question 26

Consultant	General Practitioner	Physiotherapist	Nurse
Osteopath	Chiropractor	Other Health Provider	

Question 27

Neck	Right Elbow	Left Thumb	Right Toes
Jaw	Left Elbow	Right Hip	Left Toes
Upper / Middle Back	Right Wrist	Left Hip	Right Big Toe
Right Shoulder	Left Wrist	Right Knee	Left Big Toe
Left Shoulder	Right Fingers	Left Knee	Other
Right Collarbone	Left Fingers	Right Ankle	
Left Collarbone	Right Thumb	Left Ankle	

Question 27

Number of steroid injections 0 -50+

Question 27

Number of steroid injections to train or compete 0 -50+

Question 31

A = Index finger is longer than ring finger
B = Both fingers are equal length
C = Ring finger is longer than index finger

Question 31

A = Very bow-legged	D = Knock-knee
B = Bow-legged	E = Very knock-knee
C = Normal	

Question 44

Mother	Father	Sister	Brother
Grandmother	Grandfather	Son	Daughter

Question 44

Right Shoulder	Right Elbow	Right Hip	Right Knee	Right Ankle	Other
Left Shoulder	Left Elbow	Left Hip	Left Knee	Left Ankle	

Question 44

Osteoarthritis	Other inflammatory condition	Infection	Other
Rheumatoid arthritis	Fracture	Cancer	

Question 44

Yes	No

Question 45

Mother	Father	Brother	Sister
Grandmother	Grandfather	Son	Daughter

Question 44

Neck	Right Collarbone	Right Hand / Fingers	Right Knee
Jaw	Left Collarbone	Left Hand / Fingers	Left Knee
Upper / Middle Back	Right Elbow	Right Thumb	Right Ankle
Lower Back	Left Elbow	Left Thumb	Left Ankle
Right Shoulder	Right Wrist	Right Hip	Other
Left Shoulder	Left Wrist	Left Hip	

APPENDIX J: Participant Information Sheet – Paper Version

The Olympian Study – Protecting Olympic athletes from osteoarthritis

Healthy Volunteer's Information Sheet

You are being invited to take part in this study that involves completing a questionnaire for research purposes. Before you decide whether to take part in this study, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and feel free to discuss it with your friends and family if you wish to. Ask us if there is anything that is not clear or if you would like more information. Take time to consider whether you wish to take part or not. If you decide to take part you may keep this information sheet. Thank you for reading this.

Background to the study?
We are undertaking a study of osteoarthritis in current and retired Great Britain's (GB) Olympic athletes. We aim to look at the proportion of GB Olympic athletes who are suffering from joint pain, stiffness or swelling, which are symptoms of possible joint arthritis. We want to be able to establish if athletes like you, are more likely, or less likely to experience symptoms of arthritis than people in the general population. We are also trying to establish what factors are related to this such as previous injury. It is hoped that by knowing this we can reduce the symptoms in other people. It should take us one year to collect and analyse this information.

What does the study involve?
The study involves volunteers completing a questionnaire that will take approximately 20 minutes to complete.

Why have I been chosen?
You have been invited to participate in this study because you are on the British Olympic Associations (BOA) 'Olympians' database. **We need information from GB Olympic athletes who have symptoms of osteoarthritis and from others who do not**. **Your reply will prove very valuable to this study regardless of whether or not you have any symptoms.** All athletes on the BOA Olympians database are being invited to take part in this study.

Do I have to take part?
Participation in this study is entirely voluntary and it is up to you to decide whether or not you wish to take part. If you decide to take part we request that you read this information carefully. You will not be asked to sign a consent form. By completing and returning the questionnaire it is implied that you have consented to take part.

What do I have to do?
If you do wish to participate in this study then please complete the enclosed paper questionnaire and return it using the prepaid envelope provided, or alternatively you may complete the questionnaire at **https://www.survey.bris.ac.uk/nottingham/olympians1** using your identification number as shown on the sticky label at the top of the invitation letter. This is not a drug trial. If you decide not to take part it will not affect any care you receive at your local hospital or general practice.

Will my taking part in the study be kept confidential?
We will keep your details strictly confidential. You will be identified by a unique

identification number entered at the top of your questionnaire. For this reason we do not require you to give personal details such as your name, date of birth or address. Any other personal and medical details you give will be linked to your ID number. The master file that links your name and ID number will be password protected and held by the BOA. The research institution will only have access to your ID number.

What are the possible disadvantages and risks of taking part?
We cannot guarantee your anonymity as it may be possible to identify you from the information you provide in your completed questionnaire. You will not be able to withdraw the information you have supplied in your completed questionnaire after it has been submitted. There will be no other direct risk from participating in this study. The information we obtain may help improve the treatment of people with osteoarthritis in the future.

What if something goes wrong? / Who can I complain to?
In case you have a complaint on your treatment by a member of staff or anything to do with the study, you can initially approach the Study Coordinator, Dale Cooper, Centre for Sport, Exercise and Osteoarthritis, Nottingham University Hospitals NHS Trust, Queens Medical Centre, 3rd Floor, West Block, Nottingham, NG7 2UH. Email: msxdjc@exmail.nottingham.ac.uk

If this achieves no satisfactory outcome, you should then contact the Ethics Committee Secretary, Mrs Louise Sabir, Division of Therapeutics and Molecular Medicine, D Floor, South Block, Queen's Medical Centre, Nottingham, NG7 2UH. Telephone 0115 8231063. E-mail louise.sabir@nottingham.ac.uk

What will happen to the results of the study?
The information we collect from your questionnaire will be stored for seven years in the Centre for Sport, Exercise and Osteoarthritis at the Queens Medical Centre, Nottingham. This data will be stored electronically in a secure database that is password protected. A printed copy of your completed questionnaire will also be stored under lock and key and accessed only by study personnel.

The data collected will be analysed to determine if there are any trends associated with increasing or reducing the onset of symptoms associated with osteoarthritis. It is hoped this will help us to determine the risk factors associated with the development of osteoarthritis. The results from this study will be published in scientific and medical journals. This study will also form part of a PhD qualification for Dale Cooper. The information you provide may also be used to assist other important pieces of research at the University of Nottingham.

Who is funding this study?
The University of Nottingham and Arthritis Research UK have funded this study.

Who has reviewed the study?
This study has been reviewed and approved by the University of Nottingham's Medical School Ethics Committee.

Contact for further information?
If you have any questions about the study please do not hesitate to contact Dale Cooper by telephone on 0115 8231411 or by email at msxdjc@exmail.nottingham.ac.uk.

Thank you for taking part in this study

APPENDIX K: Patient Public Involvement Interview Schedule

Meeting Date: Wednesday 05 March 2014			**Meeting Time:** 2.00 pm to 4.00 pm	**Venue:** Committee Room (2301), Nottingham Health Science Partners, C Floor, QMC	**Facilitator:** Vikki Develin	**Researcher:** Dale Cooper

No	Agenda Item	Presenter(s)	Time	Notes
1	Tea/Coffee & Introductions	All	2.00 pm (5 mins)	Group to briefly introduce themselves
2	Presentation & brief overview of research study	Dale Cooper	2.05 pm (15 mins)	Dale will present the plans for his research study
3	Discuss the questionnaire	All	2.20 pm (1 hour)	Some parts of the questionnaires cannot be changed, however there are some issues we would like to discuss. • The look and length of the questionnaire • How easy the questionnaire is to understand • What might encourage you to fill in the questionnaire? • What issues or benefits could there be with filling the questionnaire in online?
4	Discuss the letter and participant information sheet	All	3.20 pm (20 mins)	Some parts of the documents cannot be changed, however there are some issues we would like to discuss. • The look of the documents • How easy the documents are to understand • If the documents would encourage you to take part in the study
5	Any other business	All	3.40 pm (20 mins) End 4.00 pm	Time to discuss any other issues or ideas, or to continue previous discussions.

Please note, we would like to use a voice recorder during this focus group. **If you do not want your voice recorded, please let us know and we will take notes of the meeting instead.**

Researcher's Notes:

The aims of this study are:
1) To look at the number of Great Britain (GB) Olympic athletes with pain and arthritis;
2) To find out if GB Olympic athletes are more likely to develop knee pain and have joint replacement surgery;
3) To find effects linked with the start of knee pain and joint replacement in GB Olympic athletes.

It's likely that around 6.7 million adults in the UK have arthritis, which is one of the main causes of pain and disability worldwide. The related costs, pain and suffering in those with arthritis make it important to learn more about some of the things that might tell us when and why it starts. This study will invite 3000 athletes, who have taken part in a summer or winter Olympic Games for a Great Britain team, to fill out a questionnaire. The athletes will be asked to tell us about any past injuries, any pain felt in the past month, and if they've ever been diagnosed with arthritis by a doctor. The information we get from the return of the questionnaire will be used to learn more about the issues that might predict which athletes get arthritis and we may then be able to bring down the number of future athletes who get the disease.

The aim of the focus group is to review and discuss:
1) The design of the questionnaire including the drop down menus;
2) The participant information sheet;
3) The letter of invite to take part in the study.

I wish to look at the language, and format of these documents to make sure that they are in plain English. I would also like to talk about any barriers to completing an online questionnaire rather than a paper questionnaire. I would like to get the focus groups' thoughts on how to attract people to read and finish the questionnaire. I would like the focus group to discuss section eight of the questionnaire to find out if we can agree how to complete the line drawings before it goes through validation in a pilot study

APPENDIX L: Advert for Pilot Study

Injury Patterns & the Development of Osteoarthritis in GB Olympic Athletes

The University of Nottingham is working in collaboration with Arthritis Research UK (ARUK), and with the support of the British Olympic Association (BOA) and BOA Athletes' Commission, to undertake a study of osteoarthritis in Great Britain's Olympians.

We will be surveying our Olympic athletes both past and present to gather information on their sporting history, injury episodes, and symptoms (or absence there of) of osteoarthritis.

The information collected will be analysed to determine any trends associated with injury, and those who go on the develop symptoms of osteoarthritis, but also importantly those who do not; with the potential for guideline development for the treatment and prevention of osteoarthritis in later life for Great Britain Olympians.

We are seeking volunteers to assess the usability of the Olympian study questionnaire. We are also looking for volunteers to assess their own joint flexibility using a newly designed self-report measure, and to undergo a ten-minute assessment of their joint flexibility by three staff members at the University of Nottingham Teaching Hospital NHS Trust.

Your contribution to this research will be invaluable, to improve the knowledge and understanding of this condition in elite athletes, to the potential benefit of yourself, and Great Britain sport as a whole.

Many thanks in advance.

Mark Batt - Director ARUK Centre for sport, exercise and osteoarthritis

Dale Cooper – Principal Investigator, the Olympian Study

APPENDIX M: Pilot Study Participant Information Sheet

University of Nottingham
Orthopaedic, Trauma and Sports Medicine
School of Medicine
Queens Medical Centre
3rd Floor, West Block
Derby Road
Nottingham
NG7 2UH

Injury Patterns and the Development of Osteoarthritis in GB Olympic Athletes

Name of Investigators:

1. Dale Cooper, PhD student, Study Co-coordinator, The University of Nottingham, School of Clinical Sciences, Queens Medical Centre, 3rd Floor, West Block, Nottingham, NG7 2UH.
2. Dr Deborah Palmer-Green, Research Fellow, School of Medicine, Queens Medical Centre, Nottingham, NG7 2UH.
3. Professor Brigitte Scammell, Head of Division and Professor in Orthopaedics, Faculty of Medicine and Health Sciences, Queens Medical Centre, Nottingham, NG7 2UH.
4. Professor Mark Batt, Director: Arthritis Research UK Centre for Sport, Exercise and Osteoarthritis and Consultant in Sport and Exercise Medicine, Centre for Sports Medicine, Nottingham University Hospitals.

Healthy Volunteer's Pilot Study Information Sheet

You are being invited to take part in this pilot study that involves completing a questionnaire for research purposes. Before you decide whether to take part in this study, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and feel free to discuss it with your friends and family if you wish to. Ask us if there is anything that is not clear or if you would like more information. Take time to consider whether you wish to take part or not. If you decide to take part you may keep this information sheet. Thank you for reading this.

Background to the study?
We are undertaking a pilot study to assess the usability of a study questionnaire. We are asking participants to take part in one of two pilot studies. The first pilot study involves completing a study questionnaire and we will be asking for feedback in terms of how easy it was to complete, and did you understand the questions/instructions in the questionnaire. The second pilot study involves completing a self-report measure that has been designed to assess your joint flexibility. You will be requested to complete this yourself, and then you will be requested to undergo a ten-minute examination of your joint flexibility by three staff members at the University of Nottingham's NHS Teaching Hospitals.

These pilot study will allow us to determine the accuracy of our questionnaire by comparing the results. This questionnaire will then be used in a subsequent study to look at the proportion of Great Britain Olympic athletes who are suffering from joint pain, stiffness or swelling, which are symptoms of possible joint arthritis. We want to be able to establish if athletes are more likely or less likely to experience symptoms of arthritis than people in the general population. We are also trying to establish what factors are related to this such as previous injury. It is hoped that by knowing this we can reduce the symptoms in other people. It should take us one month to collect and analyse the information you give us.

What does the study involve?
The study involves volunteers completing a questionnaire that will take approximately 5 minutes to complete.

Why have I been chosen?
You have been invited to participate in this study because you are a student / staff member at the University of Nottingham. We need people like you to help us ensure the study questionnaire is complete. Your reply will prove very valuable to this study regardless of whether or not you have any symptoms.

Do I have to take part?
Participation in this study is entirely voluntary and it is up to you to decide whether or not you wish to take part. If you decide to take part we request you read this information carefully. You will not be asked to sign a consent form. By completing and returning the questionnaire it is implied that you have consented to take part.

What do I have to do?
If you do wish to participate in this pilot study then please complete the electronic questionnaire that will be given to you by the principal investigator. This is not a drug trial. If you decide not to take part it will not affect any care you receive at your local hospital or general practice.

What are the possible disadvantages and risks of taking part?
We cannot guarantee your anonymity as you maybe identified from the information you provide in your completed questionnaire. You will not be able to withdraw the information you have supplied in your completed questionnaire after it has been submitted. There will be no other direct risk from participating in this study. The information we obtain may help improve the treatment of people with osteoarthritis in the future.

What if something goes wrong? / Who can I complain to?
In case you have a complaint on your treatment by a member of staff or anything to do with the study, you can initially approach the Study Coordinator, Dale Cooper, The University of Nottingham, School of Clinical Sciences, Queens Medical Centre, 3rd Floor, West Block, Nottingham. NG7 2UH. Email: msxdjc@nottingham.ac.uk

If this achieves no satisfactory outcome, you should then contact the Ethics Committee Secretary, Mrs Louise Sabir, Division of Therapeutics and Molecular Medicine, D Floor, South Block, Queen's Medical Centre, Nottingham, NG7 2UH. Telephone 0115 8231063. E-mail louise.sabir@nottingham.ac.uk

Will my taking part in the study be kept confidential?
We will keep your details strictly confidential. You will be identified by a unique identification number entered at the top of your questionnaire. Any other personal details you give will be linked to your ID number. The master file that links your name and ID number will be password protected and held at the Arthritis Research UK Centre for Sport, Exercise and Osteoarthritis at the Queen's Medical Centre, Nottingham. Only research personnel at the named research institution will have access to the mater file.

What will happen to the results of the study?
The information we collect from your questionnaire will be stored for seven years in the Centre for Orthopaedic, Trauma and Sports Medicine at the Queens Medical Centre, Nottingham. This data will be stored electronically in a secure database that is password protected. The data collected will be analysed to assess the validity of the study questionnaire. The results from this pilot study may be published in scientific and medical journals. This study will also form part of a PhD qualification for Dale Cooper. The information you provide may also be used to assist other important pieces of research at the University of Nottingham.

Who is funding this study?
The University of Nottingham and Arthritis Research UK have funded this study.

Who has reviewed the study?
This study has been reviewed and approved by the University of Nottingham Medical School Ethics Committee.

Contact for further information?
If you have any questions about the study please do not hesitate to contact Dale Cooper by email at: msxdjc@nottingham.ac.uk. Thank you for taking part in this study.

APPENDIX N: Pilot Study Consent Form

University of Nottingham, School of Medicine, Division of Health Sciences

Injury Patterns and the Development of Osteoarthritis in GB Olympic Athletes

Dale Cooper (Principal Investigator)

Healthy Volunteer's Consent Form

Please read this form and the above designated representative will fully explain the aims and procedures of the study to you. Participation in this study is entirely voluntary and it is up to you to decide whether or not you wish to take part.

If you decide to take part we request that you read the attached participant information sheet carefully. You will not be asked to sign this consent form. By completing and returning the questionnaire implies that you have consented to take part and agree to the following:

I voluntarily agree to take part in this study.

I have been given a full explanation by the above named and I have read and understand the information sheet that is attached.

I have been given the opportunity to ask questions and discuss the study with the above investigator on all aspects of the study and have understood the advice and information given as a result.

I agree to comply with the reasonable instructions of the supervising investigator and I authorise the investigator to disclose the results of my participation in the study but not my name.

I understand that information about me recorded during the study will be kept in a secure database. If data is transferred to others it will be made anonymous. Data will be kept for 7 years after the results of this study have been published.

I understand that I can ask for further instructions or explanations at any time.

I understand that I am free to withdraw from the study at any time, without having to give a reason for withdrawing.

I confirm that I have disclosed relevant medical information before the study.

Study Volunteer Number: ……

Investigators Signature: ……... **Date**:

Investigators Name:…….

APPENDIX O: Participant Information Sheet – Web-Version

The Olympian Study

Healthy Volunteer's Information Sheet

You are being invited to take part in this study that involves completing a questionnaire for research purposes. Before you decide whether to take part in this study, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and feel free to discuss it with your friends and family if you wish to. Ask us if there is anything that is not clear or if you would like more information. Take time to consider whether you wish to take part or not. If you decide to take part you may keep this information sheet. Thank you for reading this.

Background to the study?
We are undertaking a study of osteoarthritis in current and retired Great Britain's (GB) Olympic athletes. We aim to look at the proportion of GB Olympic athletes who are suffering from joint pain, stiffness or swelling, which are symptoms of possible joint arthritis. We want to be able to establish if athletes like you, are more likely, or less likely to experience symptoms of arthritis than people in the general population. We are also trying to establish what factors are related to this such as previous injury. It is hoped that by knowing this we can reduce the symptoms in other people. It should take us one year to collect and analyse this information.

What does the study involve?
The study involves volunteers completing a questionnaire that will take approximately 20 minutes to complete.

Why have I been chosen?
You have been invited to participate in this study because you are on the British Olympic Associations (BOA) 'Olympians' database. **We need information from GB Olympic athletes who have symptoms of osteoarthritis and from others who do not**. **Your reply will prove very valuable to this study regardless of whether or not you have any symptoms.** All athletes on the BOA Olympians database are being invited to take part in this study.

Do I have to take part?
Participation in this study is entirely voluntary and it is up to you to decide whether or not you wish to take part. If you decide to take part we request that you read this information carefully. You will not be asked to sign a consent form. By completing and returning the questionnaire it is implied that you have consented to take part.

What do I have to do?
If you do wish to participate in this study then please complete the questionnaire at **https://www.survey.bris.ac.uk/nottingham/olympians** using your identification number as shown on the email that the British Olympic Association Athletes' Commission sent to you inviting you to complete the questionnaire. Alternatively, if you would like a paper copy of the questionnaire one will be sent to you automatically in late June 2014 should you have not replied to the online questionnaire. This is not a drug trial. If you decide not to take part it will not affect any care you receive at your local hospital or general practice.

Will my taking part in the study be kept confidential?
We will keep your details strictly confidential. You will be identified by a unique identification number entered at the top of your questionnaire. For this reason we do not require you to give personal details such as your name, date of birth or address. Any other personal and medical details you give will be linked to your ID number. The master file that links your name and ID number will be password protected and held by the BOA. The research institution will only have access to your ID number.

What are the possible disadvantages and risks of taking part?
We cannot guarantee your anonymity as it may be possible to identify you from the information you provide in your completed questionnaire. You will not be able to withdraw the information you have supplied in your completed questionnaire after it has been submitted. There will be no other direct risk from participating in this study. The information we obtain may help improve the treatment of people with osteoarthritis in the future.

What if something goes wrong? / Who can I complain to?
In case you have a complaint on your treatment by a member of staff or anything to do with the study, you can initially approach the Study Coordinator, Dale Cooper, Centre for Sport, Exercise and Osteoarthritis, Nottingham University Hospitals NHS Trust, Queens Medical Centre, 3rd Floor, West Block, Nottingham. NG7 2UH. Email: msxdjc@exmail.nottingham.ac.uk

If this achieves no satisfactory outcome, you should then contact the Ethics Committee Secretary, Mrs Louise Sabir, Division of Therapeutics and Molecular Medicine, D Floor, South Block, Queen's Medical Centre, Nottingham, NG7 2UH. Telephone 0115 8231063. E-mail louise.sabir@nottingham.ac.uk

What will happen to the results of the study?

The information we collect from your questionnaire will be stored for seven years in the Centre for Sport, Exercise and Osteoarthritis at the Queens Medical Centre, Nottingham. This data will be stored electronically in a secure database that is password protected. A printed copy of your completed questionnaire will also be stored under lock and key and accessed only by study personnel.

The data collected will be analysed to determine if there are any trends associated with increasing or reducing the onset of symptoms associated with osteoarthritis. It is hoped this will help us to determine the risk factors associated with the development of osteoarthritis. The results from this study will be published in scientific and medical journals. This study will also form part of a PhD qualification for Dale Cooper. The information you provide may also be used to assist other important pieces of research at the University of Nottingham.

Who is funding this study?
The University of Nottingham and Arthritis Research UK have funded this study.

Who has reviewed the study?
This study has been reviewed and approved by the University of Nottingham Medical School Ethics Committee.

Contact for further information?
If you have any questions about the study please do not hesitate to contact Dale Cooper by telephone on 0115 8231411 or by email at msxdjc@exmail.nottingham.ac.uk.

Thank you for taking part in this study

APPENDIX P: Codebook For Data Analysis

Table 88: Example of Code Book for Data Analysis

VARIABLE	SPSS VARIABLE NAME	CODING INSTRUCTIONS
Participants unique identification number	ID Number	1 to 2883
Age in years	Age	a) Coded age in years b) Coded as: 0 = 40-59 years; 1 = 60 years and over
Gender	Sex	0 = Male; 1 = Female
Body mass index	BMI	a) Coded as continuous data b) Coded as 1 = underweight / normal weight < 25.00; 2 = over weight ≥ 25.00-29.99; and obese ≥ 30.00 c) Coded as 1 = underweight < 18.50; 2 = normal weight ≥ 18.50-24.99; 3 = over weight ≥ 25.00-29.99; and 4 = obese ≥ 30.00
Occupational athletic activity	Sport - WB	0 = Non-weight-bearing loading-sport; 1 = Weight-bearing loading-sport
Generalised joint hypermobility in 20s	GJH 20s	0 = No (Beighton 0-3/9); 1 = Yes (Beighton 4-9/9)
Comorbidities	Comorbidities	0 = No; 1 = Yes (1 comorbidity); 2 = Yes (2 or more comorbidities)
Index ring finger ratio	2D:4D	0 = Equal length 1 = Index longer than ring finger 2 = Index shorter than ring finger
Finger nodes	Nodes	0 = No; 1 = Yes
Knee alignment	Knee align	0 = Normal; 1 = Varus; 2 = Valgus

APPENDIX Q: Scoring Algorithm to Score the 12-item Short Form Health Survey

Response Choice(s) (Items)	Indicator Variable	Physical Weight	Mental Weight
Moderate Activities (PF02)			
Limited a lot	PF02_1	-7.23216	3.93115
Limited a little	PF02_2	-3.45555	1.86840
Climbing several flights of stairs (PF04)			
Limited a lot	PF04_1	-6.24397	2.68282
Limited a little	PFO4_2	-2.73557	1.43103
Accomplish less than you would like (RP2)			
Yes	RP2_1	-4.61617	1.44060
Limited in the kind of activities (RP3)			
Yes	PR3_1	-5.51747	1.66968
Pain interferes with normal work (BP2)			
Extremely	BP2_1	-11.25544	1.48619
Quite a bit	BP2_2	-8.38063	1.76691
Moderately	BP2_3	-6.50522	1.49384
A little bit	BP2_4	-3.80130	0.90384
In general, would you say your health is (GH1)	GH1_1	-8.37399	-1.71175
Poor	GH1_2	-5.5646§	-0.16891
Fair	GH1_3	-3.02396	0.03482
Good	GH1_4	-1.31872	-0.06064
Very good			
Have a lot of energy (VT2)			
None of the time	VT2_1	-2.44706	-6.02409
A little of the time	VT2_2	-2.02168	-4.88962
Some of the time	VT2_3	-1.61850	-3.29805
A good bit of the time	VT2_4	-1.14387	-1.65178
Most of the time	VT2_5	-0.422251	-0.92057
Health interferes with social activities (SF2)			
All of the time	SF2_1	-0.33682	-6.29724
Most of the time	SF2_2	-0.94342	-8.26066
Some of the time	SF2_3	-0.18043	-5.63286
A little of the time	SF2_4	0.11038	-3.13896
Accomplish less than you would like (RE2)			
Yes	RE2_1	3.04365	-6.82672
Didn't do activities as carefully as usual (RE3)	RE3_1	2.32091	-5.69921
Yes			
Felt calm and peaceful (MH3)			
None of the time	MH3_1	3.46638	-10.19085
A little of the time	MH3_2	2.90426	-7.92717
Some of the time	MH3_3	2.37241	-6.31121
A good bit of the time	MH3_4	1.36689	-4.09842
Most of the time	MH3_5	0.66514	-1.94949
Felt downhearted and blue (MH4)			
All of the time	MH4_1	4.61446	-16.15395
Most of the time	MH4_2	3.41593	-10.77911
A good bit of the time	MH4_3	2.34247	-8.09914
Some of the time	MH4_4	1.28044	-4.59055
A little of the time	MH4_5	0.41188	-1.95934
Constant (1990)	-	56.57706	60.75781
Constant (1998)	-	57.65693	60.58847

Ref: Ware et al (2002)

APPENDIX R: Protocol for Goniometry Assessment

Instrumentation: A plastic goniometer with moveable arms marked in 1-degree increments. One physiotherapist, sticky markers, one chair, one room with a treatment couch and one 600-millimetre tape measure.

Procedure for assessment: Goniometric measurements for the elbow, knee, 1st carpalmetacarpal and 5th metacarpalphalangeal joints are to be performed according to the technique described by Norkin and White (1995). No protocol is given for visual estimation. The examiner is to record one attempt for each measurement and to place the scorecard in the sealed box. The examiner was informed not to discuss any measure with the participants. Sticky markers are to be placed over the bony landmarks described as reference points in the goniometry alignment procedure described below. The examiner is to assess the following:

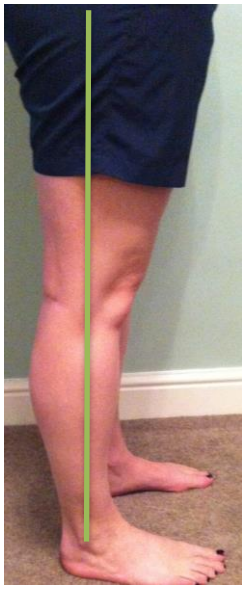
1. Knee Extension

Testing Position (see Photograph 1):
The subject is standing, with the hip in 0 degrees of abduction, adduction, flexion, extension, and rotation.

Goniometer Alignment:

I. Center the fulcrum of the goniometer over the lateral epicondyle of the femur.
II. Align the proximal arm with the lateral midline of the femur, using the greater trochanter for reference (apply sticky marker).
III. Align the distal arm with the lateral midline of the fibula, using the lateral malleolus and fibula head for reference (apply sticky marker).

Photograph 1 – Knee Joint Goniometry Assessment



2. Metacarpalphalangeal (MCP) 5th Joint Extension

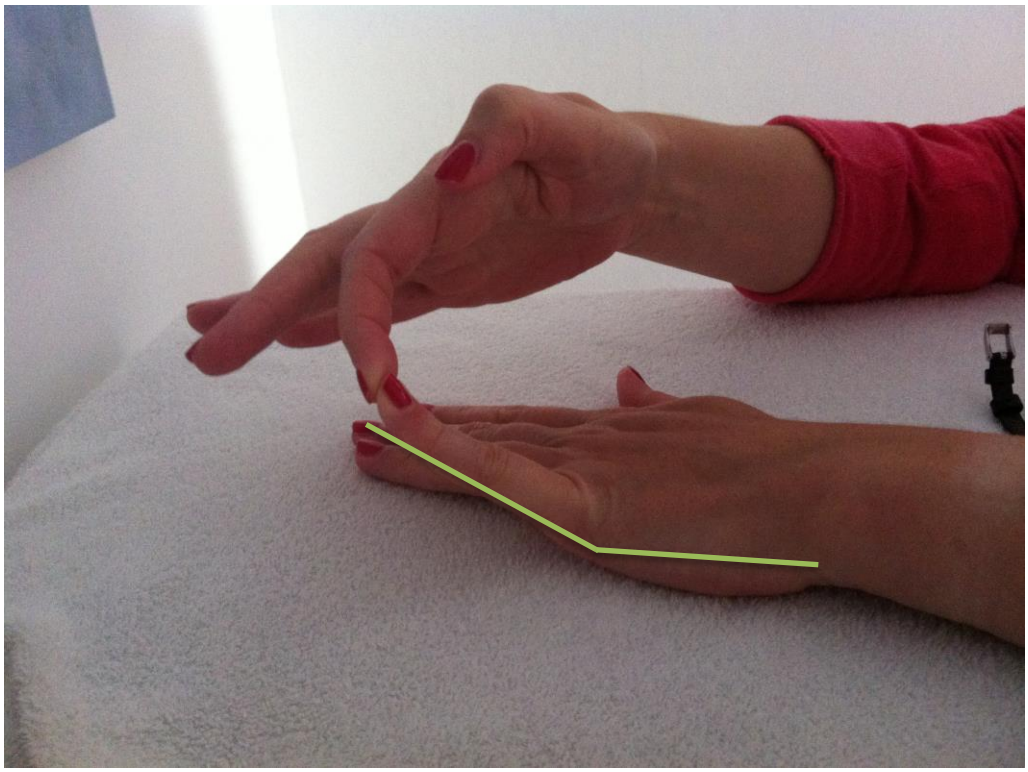
Testing Position (see photograph 2):
Position the subject in sitting, with the forearm pronated. The wrist is positioned in 0 degrees of flexion, extension, ulnar and radial deviation. The forearm and hand rest on a supporting surface. The MCP joint being examined should be in a neutral position relative to abduction and adduction.

Goniometer Alignment:

I. Center the fulcrum of the goniometer over the dorsal aspect of the MCP joint.
II. Align the proximal arm over the dorsal midline of the metacarpal.
III. Align the distal arm over the dorsal midline of the proximal phalanx.

Photograph 2 – Metacarpalphalangeal Joint Goniometry

Assessment



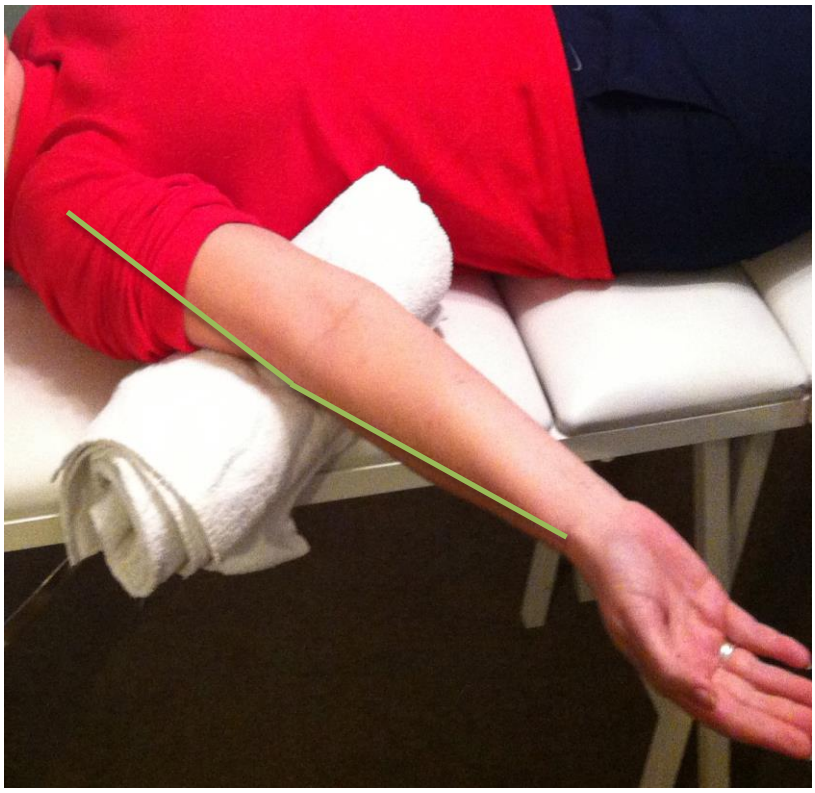
3. Elbow Extension

Testing Position (see photograph 3):
Position the subject supine, with the shoulders in 0 degrees of flexion, extension, and abduction so that the arm is closed to the side of the body. A pad / towel is placed under the distal end of the humerus to allow for full elbow extension. The forearm is positioned in full supination with the palm of the hand facing the ceiling.

Goniometer Alignment:

I. Centre the fulcrum of the goniometer over the lateral epicondyle of the humerus (apply sticky marker).
II. Align the proximal arm with the lateral midline of the humerus, using the centre of the acromial process for reference (apply sticky marker).
III. Align the distal arm with the lateral midline of the radius, using the radial head and radial styloid process for reference (apply sticky marker).

Photograph 3 – Elbow Joint Goniometry Assessment



4. Lumbar Spine Flexion

Testing Position (see photograph 4):
Position the subject in standing with the knees extended. The subject is requested to reach with both fingertips to place the palm of their hands on the floor or as close as possible whilst keeping their knees extended.

Measurement:

I. Measure the distance between the 3rd fingertips on both hands vertically to the floor in millimetres using the goniometer ruler.
II. Should the ruler not be sufficient to measure the gap between the fingertips and the floor you are instructed to use the tape measure provided.

Photograph 4 – Lumbar Spine Measurement

5. Thumb Abduction

Testing Position (see photograph 5):
Position the subject in sitting, with the forearm midway between pronation and supination. The wrist is positioned in 0 degrees of flexion, extension, and radial and ulnar deviation.

Measurement:

I. Request the subject uses their opposite hand to extend and abduct their thumb to rest on their forearm or as close as possible (see photograph 5).
II. Measure the distance between the thumb pad on the dorsal aspect of the distal phalanx and the forearm horizontally in millimetres using the goniometer ruler.

Photograph 5 – Thumb Joint Abduction Measurement

APPENDIX S: Scoring Card for the Development and Validation of the Self-Report Beighton Instrument

Participant ID Number:

Therapists Initials:

Goniometry Assessment	**Right Limb 1st attempt**	**Right Limb 2nd attempt**	**Right Limb 3rd attempt**	**Left Limb 1st attempt**	**Left Limb 2nd attempt**	**Left Limb 3rd attempt**
Knee Extension						
2nd MCP Extension						
Elbow Extension						
Thumb abduction						
	1st attempt	2nd attempt	3rd attempt			
Lumbar Spine Flexion						

APPENDIX T: Results of Fitting Interactions to the Main Effects Multivariable Regression Models for Pain and Self-Reported Physician-Diagnosed Osteoarthritis

Table 89: Results of Fitting Interactions to the Main Effects Multivariable Knee Pain Model

	Coeff.	Std.Err.	*p*	OR	95% CI
Age*Gender	-0.01	0.02	0.52	0.99	0.95, 1.02
Age*Widespread pain	-0.00	0.02	0.98	1.00	0.97, 1.04
Age*Knee injury	-0.02	0.02	0.41	0.98	0.94, 1.02
Body mass index*Gender	-0.11	0.06	0.07	0.90	0.80, 1.01
Body mass index*Knee injury	0.02	0.08	0.80	1.02	0.88, 1.18
Body mass index*Widespread pain	-0.03	0.06	0.57	0.97	.086, 1.08
Gender*Knee injury	0.17	0.56	0.76	1.19	0.40, 3.52
Knee injury*Sports W.B	0.30	0.62	0.63	1.35	0.40, 4.51
Knee injury*Widespread pain	0.07	0.64	0.91	1.08	0.31, 3.75

Pearson chi-square used for categorical variables with two levels. **Pearson linear-by-linear reported on for ordinal categorical data. ***Independent-samples t-test used for continuous data.

Table 90: Results of Fitting Interactions to the Main Effects Multivariable Regression Hip Pain Model

	Coeff.	Std.Err.	*p*	OR	95% CI
Age*Gender	-0.004	0.02	0.83	1.00	0.96, 1.03
Age*Hip injury	-0.01	0.04	0.73	0.99	0.92, 1.06
Body mass index*Gender	0.04	0.06	0.46	1.04	0.93, 1.16
Body mass index*Hip injury	0.04	0.16	0.78	1.05	0.76, 1.43
Gender*Hip injury	0.08	1.24	0.95	1.08	0.10, 12.25
Hip injury*SF-12 PCS	0.03	0.62	0.96	1.03	0.31, 3.44
Sports W.B.*SF-12 PCS	0.01	0.02	0.57	1.01	0.97, 1.06

Pearson chi-square used for categorical variables with two levels. **Pearson linear-by-linear reported on for ordinal categorical data. ***Independent-samples t-test used for continuous data.

Table 91: Results of Fitting Interactions to the Main Effects Multivariable Regression Lumbar Spine Pain Model

	Coeff.	Std.Err.	*p*	OR	95% CI
Age*Lumbar spine injury	0.01	0.02	0.73	1.01	0.97, 1.05
Body mass index*Gender	0.00	0.05	0.998	1.00	0.90, 1.11
Body mass index*Lumbar spine injury	0.04	0.06	0.49	1.05	0.92, 1.18
Gender*Lumbar spine Injury	-0.47	0.49	0.34	0.62	0.24, 1.63
Lumbar spine injury*SF-12 PCS	0.02	0.02	0.42	1.02	0.97, 1.07

Pearson chi-square used for categorical variables with two levels. **Pearson linear-by-linear reported on for ordinal categorical data. ***Independent-samples t-test used for continuous data.

Table 92: Results of Fitting interactions to the Main Effects Multivariable Regression Knee Osteoarthritis Model

	Coeff.	Std.Err.	*p*	aOR	95% CI
Hypermobility (20-29 years)*Age	0.01	0.03	0.85	1.01	0.95, 1.07
Hypermobility (20-29 years)*Gender	0.38	0.76	0.62	1.46	0.33, 6.51
Hypermobility (20-29 years)*Injury	1.01	0.80	0.21	2.73	0.58, 12.98
Body mass index*Gender	-0.12	0.07	0.037	40.89	0.77, 1.02
Body mass index*Age	0.01	0.004	0.01	1.01	1.00, 1.02
Injury*Gender	0.99	0.64	0.13	2.68	0.76, 9.45

Pearson chi-square used for categorical variables with two levels. **Pearson linear-by-linear reported on for ordinal categorical data. ***Independent-samples t-test used for continuous data.

Table 93: Results of Fitting Interactions to the Main Effects Multivariable Regression Hip Osteoarthritis Model

	Coeff.	Std.Err.	*p*	OR	95% CI
Age*Body Mass Index	0.003	0.004	0.46	1.00	1.00, 1.01
Body Mass Index*Gender	-0.26	0.11	0.02	0.77	0.62, 0.95
Gender*Hip Injury	-0.15	1.12	0.90	0.86	0.10, 7.75

Pearson chi-square used for categorical variables with two levels. **Pearson linear-by-linear reported on for ordinal categorical data. ***Independent-samples t-test used for continuous data.

Table 94: Results of Fitting interactions to the Main Effects Multivariable Regression lumbar Spine Osteoarthritis Model

	Coeff.	Std.Err.	*p*	OR	95% CI
Age*Body Mass Index	-0.01	0.05	0.85	0.99	0.90, 1.09
Body Mass Index*Gender	-0.01	0.05	0.76	0.99	0.90, 1.08
Age*Gender	0.27	0.02	0.12	1.03	0.99, 1.06

Pearson chi-square used for categorical variables with two levels. **Pearson linear-by-linear reported on for ordinal categorical data. ***Independent-samples t-test used for continuous data.

APPENDIX U: Statistical Output from Checking for Multicollinearity

Table 95: Correlations Between Covariates and Knee Pain

		Knee Pain	Age	BMI	Gender	Knee Injury	Sports W.B	Knee alignment	Widespread Pain	Total PCS
Pearson Correlation	Knee Pain	1.00	0.09	0.18	0.02	0.15	0.11	0.02	0.15	-0.26
	Age	0.09	1.00	0.07	-0.29	-0.09	0.09	0.01	-0.06	-0.41
	BMI	0.18	0.07	1.00	-0.21	0.03	0.03	0.002	0.10	-0.22
	Gender	0.02	-0.29	-0.21	1.00	0.04	-0.13	-0.02	-0.02	0.01
	Knee Injury	0.15	-0.09	0.03	0.04	1.00	0.09	0.02	-0.03	0.03
	Sports W.B	0.11	0.09	0.03	-0.13	0.09	1.00	0.01	0.01	-0.002
	Knee alignment 20s	0.02	0.01	0.002	-0.02	0.02	0.01	1.00	-0.01	-0.02
	Widespread Pain	0.15	-0.06	0.10	-0.02	-0.03	0.01	-0.01	1.00	-0.21
	Total PCS	-0.26	-0.41	-0.22	0.01	0.03	-0.002	-0.02	-0.21	1.00

Table 96: Coefficients Between Covariates and Knee Pain

Model	Unstandardised Coefficents		Standardised Coefficients			Collinearity Statistics	
	B	Std. Error	Beta	t	Sig.	Tolerance	VIF
Constant	0.20	0.25		0.79	0.43		
Age	0.001	0.002	0.02	0.41	0.68	0.71	1.40
BMI	0.02	0.01	0.13	2.94	0.003	0.90	1.11
Gender	0.06	0.04	0.07	1.51	0.13	0.84	1.19
Knee Injury	0.18	0.05	0.15	3.59	0.00	0.98	1.02
Sports W.B	0.09	0.04	0.10	2.47	0.01	0.97	1.03
Knee alignment 20s	0.01	0.04	0.01	0.29	0.77	0.998	1.00
Widespread pain	0.10	0.04	0.10	2.35	0.02	0.92	1.08
Total PCS	-0.01	0.002	-0.21	-4.39	0.00	0.72	1.38

Table 97: Correlations Between Covariates and Hip Pain

		Hip Pain	Age	BMI	Gender	Hip Injury	Sports W.B	SF-12 PCS
Pearson Correlation	Hip Pain	1.00	0.05	0.04	-0.01	0.16	0.11	-0.02
	Age	0.05	1.00	0.07	-0.29	0.03	0.09	-0.41
	BMI	0.04	0.07	1.00	-0.02	-0.01	0.03	-0.02
	Gender	-0.01	-0.29	-0.21	1.00	-0.003	-0.13	0.01
	Hip Injury	0.16	0.03	-0.01	-0.03	1.00	0.07	-0.04
	Sports W.B	0.11	0.09	0.03	-0.13	0.07	1.00	-0.002
	SF-12 PCS	-0.18	-0.41	-0.22	0.01	-0.04	-0.002	1.00

Table 98: Coefficients Between Covariates and Hip Pain

	Unstandardised Coefficients		Standardised Coefficients			Collinearity Statistics	
Model	B	Std. Error	Beta	t	Sig.	Tolerance	VIF
Constant	0.70	0.24		2.99	0.003		
Age	-0.002	0.002	-0.05	-1.07	0.29	0.74	1.35
BMI	0.00	0.01	-0.002	-0.04	0.97	0.90	1.11
Gender	-0.004	0.04	-0.004	-0.10	0.92	0.85	1.18
Hip Injury	0.34	0.10	0.14	3.42	0.001	0.99	1.01
Sports W.B	0.09	0.04	0.10	2.38	0.02	0.97	1.03
SF-12 PCS	-0.01	0.002	-0.20	-4.19	0.00	0.77	1.30

Table 99: Correlations Between Covariates and Lumbar Spine Pain

		L.Spine Pain	Age	BMI	Gender	L.Spine Injury	Finger nodes	SF-12 PCS
Pearson Correlation	L.Spine Pain	1.00	-0.08	0.09	0.02	0.19	0.10	-0.02
	Age	-0.08	1.00	0.07	-0.29	-0.14	0.08	-0.41
	BMI	0.09	0.07	1.00	-0.21	-0.01	0.01	-0.22
	Gender	0.02	-0.29	-0.21	1.00	0.10	0.16	-0.01
	L. Spine Injury	0.19	-0.14	-0.01	0.10	1.00	0.003	-0.01
	Finger nodes	0.10	0.08	0.01	0.16	0.003	1.00	-0.19
	Total PCS	-0.20	-0.41	-0.22	0.01	-0.01	-0.19	1.00

Table 100: Coefficients Between Covariates and Lumbar Spine Pain

	Unstandardised Coefficients		Standardised Coefficients			Collinearity Statistics	
Model	B	Std. Error	Beta	t	Sig.	Tolerance	VIF
Constant	1.20	0.26		4.68	0.001		
Age	-0.01	0.002	-0.19	-3.94	0.001	0.73	1.37
BMI	0.01	0.01	0.04	0.95	0.34	0.92	1.11
Gender	-0.05	0.04	-0.05	-1.05	0.29	0.83	1.21
L/Spine Injury	0.21	0.05	0.17	4.06	0.001	0.97	1.03
Finger nodes	0.13	0.08	0.07	1.63	0.10	0.93	1.07
SF-12 PCS	-0.01	0.002	-0.26	-5.45	0.001	0.75	1.33

Table 101: Correlations Between Covariates and Self-Reported Physician-Diagnosed Knee Osteoarthritis

		OA Any Knee (0 = No; 1 = Yes)	Age	BMI	Gender	Knee Injury	Hypermobility (20-29 years)
Pearson Correlation	OA Any Knee	1.00	0.22	0.10	-0.03	0.019	0.10
	Age	0.22	1.00	0.07	-0.29	-0.09	-0.12
	BMI	0.10	0.07	1.00	-0.21	0.03	0.01
	Gender	-0.03	-0.29	-0.21	1.00	0.04	0.18
	Knee Injury	0.19	-0.09	0.03	0.04	1.00	0.05
	Hypermobility (20—29 years)	0.10	-0.12	0.01	0.18	0.05	1.00

Table 102: Coefficients Between Covariates and Self-Reported Physician-Diagnosed Knee Osteoarthritis

Model	Unstandardized Coefficients		Standardised Coefficients			Collinearity Statistics	
	B	Std. Error	Beta	t	Sig.	Tolerance	VIF
Constant	-0.52	0.13		-3.96	0.001		
Age	0.01	0.001	0.25	5.56	0.001	0.91	1.10
BMI	0.01	0.004	0.08	1.88	0.06	0.95	1.05
Gender	0.02	0.03	0.03	0.60	0.55	0.86	1.16
Knee Injury	0.20	0.04	0.21	4.80	0.001	0.99	1.01
Hypermobility (20-29 years)	0.11	0.04	0.11	2.57	0.01	0.96	1.04

Table 103: Correlations Between Covariates and Self-Reported Physician-Diagnosed Hip Osteoarthritis

		OA Any Hip (0 = No; 1 = Yes)	Age	BMI	Gender	Hip Injury
Pearson Correlation	OA Any Hip	1.00	0.23	0.01	-0.06	0.22
	Age	0.23	1.00	0.07	-0.29	0.03
	BMI	0.007	0.07	1.00	-0.21	-0.01
	Gender	-0.06	-0.29	-0.21	1.00	-0.03
	Hip Injury	0.22	0.03	-0.01	-0.03	1.00

Table 104: Coefficients Between Covariates and Self-Reported Physician-Diagnosed Hip Osteoarthritis

	Unstandardised Coefficients		Standardised Coefficients			Collinearity Statistics	
Model	B	Std. Error	Beta	t	Sig.	Tolerance	VIF
Constant	-0.24	0.11		-2.13	0.03		
Age	0.01	0.001	0.23	5.45	0.00	0.92	1.09
BMI	0.00	0.003	-0.01	-0.13	0.90	0.96	1.05
Gender	0.01	0.03	0.01	0.20	0.84	0.88	1.13
Knee Injury	0.37	0.07	0.21	5.32	0.00	0.998	1.002

Table 105: Correlations Between Covariates and Self-Reported Physician-Diagnosed Lumbar Spine Osteoarthritis

		Lumbar Spine OA (0 = No; 1 = Yes)	Age	BMI	Gender
Pearson Correlation	Lumbar Spine OA	1.00	0.10	0.003	0.14
	Age	0.10	1.00	0.07	-0.29
	BMI	0.003	0.07	1.00	-.021
	Gender	0.14	-0.29	-0.21	1.00

Table 106: Coefficients Between Covariates and Self-Reported Physician-Diagnosed Lumbar Spine Osteoarthritis

	Unstandardised Coefficients		Standardised Coefficients			Collinearity Statistics	
Model	B	Std. Error	Beta	t	Sig.	Tolerance	VIF
Constant	-0.19	0.08		-2.41	0.02		
Age	0.002	0.001	0.15	3.53	0.001	0.92	1.09
BMI	0.002	0.002	0.03	0.79	0.43	0.96	1.05
Gender	0.08	0.02	0.19	4.37	0.001	0.88	1.13

APPENDIX V: Covariates Entered into Logistic Regression Models for Pain and Osteoarthritis at the Hip, Knee, and the Lumbar Spine

Table 107: Covariates entered into Logistic Regression

	PAIN			OSTEOARTHRITIS		
	Knee	Hip	Lumbar	Knee	Hip	Lumbar
Age	✓	✓	✓	✓	✓	✓
BMI	✓	✓	✓	✓	✓	✓
Gender	✓	✓	✓	✓	✓	✓
Prior injury	✓	✓	✓	✓	✓	✓
Knee mal-alignment	✓	✓	✓	✓	✓	✓
Sport W.B.	✓	✓	✓	✓	✓	✓
Hypermobility	✓	✓	✓	✓	✓	✓
Comorbidities	✓	✓	✓	✓	✓	✓
2D: 4D	✓	✓	✓	✓	✓	✓
Finger nodes	✓	✓	✓	✓	✓	✓
Sport: impact	✓	✓	✓	✓	✓	✓
LBP	✓					
Hip pain	✓					
Widespread pain	✓					
SF-12 MCS	✓	✓	✓			
SF-12 PCS	✓	✓	✓			