Available online at www.sciencedirect.com
SCIENCE DIRECT®
Physical Therapy in Sport 7 (2006) 101–109
Physical Therapy in sport
www.elsevier.com/locate/yptsp

Review

# Prospective studies into the causation of hamstring injuries in sport: A systematic review

T.K. Foreman*, T. Addy[1], S. Baker[2], J. Burns[2], N. Hill[3], T. Madden[4]

*Faculty of Health and Social Care, University of the West of England, Blackberry Hill, Stapleton, Bristol, BS16 1DD, UK*

Received 28 January 2005; received in revised form 28 October 2005; accepted 13 February 2006

**Abstract**

*Aim:* To identify and determine specific predisposing factors related to hamstring injuries in sport.
*Method:* Systematic review.
*Data sources:* Key word search of seven databases (AMED, Cochrane Systematic Review Database, EMBASE, MEDLINE, PEDro, SMART and SPORTDiscuss). Four concepts with key words and truncated key words were used in the search. Other methods used included hand searching, snowballing and personal communication.
*Results:* The search strategy implemented generated two experimental studies and five observational studies which were reviewed. All seven papers considered predictive factors for injury with varying results. Limited evidence was apparent linking pre-season neuromuscular proprioception, age, race, pre-season hamstring/quadriceps muscle strength and a past history of injury as predictive variables for subsequent hamstring injury. The most conflicting findings were the predictive values of hamstring strength and previous hamstring injury.
*Conclusion:* Risk factors identified by the studies were conflicting and no single risk factor was found to be consistently associated with hamstring injury. This may in part be due to the wide variety in research methodologies which hinders comparisons between studies being made.

Further research using larger cohorts and measuring a broader range of variables is required to reflect the multi-factorial nature of hamstring injury. From this it may be possible to establish consistent risk factors associated with hamstring injury in order to design preventative and rehabilitative programmes in the sporting arena.


*Keywords:* Systematic review; Hamstring; Injury; Sport

## 1. Introduction

Hamstring injuries (HSI) have frequently been identified as the most common injury in running and sprinting athletes (Drezner, 2003; Orchard, Marsden, Lord, & Garlick, 1977), as well as in Soccer (Askling, Karlsson, & Thorstensson, 2003), Rugby Union (Upton, Noakes, & Juritz, 1996) and Australian Rules Football (ARF) (Orchard et al., 1977; Bennell et al., 1998; Cameron, Adams, & Maher, 2003). In an official audit of injuries in English professional football, HSI has been shown to account for 12%–15% of all injuries sustained (Hawkins, Hulse, Wilkinson, Hodson, & Gibson, 2001; Woods et al., 2004). The study of 2376 players showed a total of 13,116 days and 2029 matches missed over the course of two seasons due solely to HSI (Woods et al., 2004). It is claimed that 10% of all major league soccer players sustain a hamstring injury during any one season (Askling et al., 2003). In the current English Premier Football League season 2005–2006, one premiership club had sustained 16 HSIs within the first three months of the season. In ARF HSI has also been highlighted as

*Corresponding author.
[1]Taunton and Somerset NHS Trust.
[2]North Bristol NHS Trust.
[3]Calderdale Royal Hospital NHS Trust.
[4]Oxford Radcliffe Hospitals Trust.

1466-853X/$ - see front matter © 2006 Published by Elsevier Ltd.
doi:10.1016/j.ptsp.2006.02.001

the most common and prevalent injury, accounting for six injuries per club, per season and resulting in 21 missed matches per club, per season (Orchard & Seward, 2002). A study carried out by Askling et al. (2003) found that 47% of all muscle strains encountered by soccer players during training and/or matches were injuries to the hamstring muscles.

Such significant figures have obvious implications, not just for the athletes themselves in terms of considerable pain and disability but also for the clubs and teams for which they are competing. Players are said to be the most important assets to the success of professional teams; not only do injuries impact on performance, results and team morale, but ultimately also the financial state of the club (Woods et al., 2004). It is estimated that the average loss of output of premier and football league clubs during the 1999–2000 soccer season due to injury alone may be as much as £74.7 million (Woods, Hawkins, Hulse, & Hodson, 2002). Furthermore, the cost of medical fees increased insurance premiums and reduced match attendance due to absence of first choice players may further raise the overall financial impact of injury (Woods et al., 2004).

The hamstrings are a two-joint muscle bulk comprised of the semimembranosus, semitendinosus and biceps femoris muscles and predominantly made up of Type II fast-twitch muscle fibres (Tortora and Grabowski, 2003). It is thought that hamstring muscle strains most commonly occur during the latter part of the swing phase where the muscle bulk reaches maximal elongation acting eccentrically to decelerate hip and knee extension in preparation for heel strike (Drezner, 2003). This may be why HSIs are particularly prevalent in sports involving activities such as sprinting, acceleration, deceleration, rapid change in direction and jumping (Devlin, 2000; Drezner, 2003).

Despite intensive rehabilitation efforts following HSI, this muscle complex appears to be particularly susceptible to re-injury (Devlin, 2000). In ARF, hamstring injuries were shown to have the highest recurrence rate of all injuries, 34% of which recurred within the same season (Orchard and Seward, 2002). It is unclear whether re-injury is due to properties intrinsic to this particular muscle group, (such as low healing rate), an original risk factor that is still active, or inadequate rehabilitation of the initial injury and/or premature return to play (Upton, Noakes, & Juritz, 1996). Such evidence shows that there is a real need to establish the possible causes of an initial HSI and the mechanism for re-injury in order to help in the design of preventative training strategies and adequate rehabilitation programmes.

Many risk factors for HSI have been implicated, including; hamstring weakness, muscle fatigue, inadequate warm-up, reduced hamstring flexibility, poor running technique, muscle imbalance (Agre, 1985), poor lumbar posture (Verrall, Slavotinek, Barnes, Fon, & Spriggins, 2001) and poor neuromuscular control (Devlin, 2000). However, research evidence to substantiate these associations is limited and findings are often conflicting (Woods et al., 2002). Information regarding risk factors is often collected retrospectively in order to establish the cause. Such studies are fundamentally flawed as it is impossible to deduce whether the variable measured is a cause or effect of the HSI (Bahr and Holme, 2003). It is clear, then, that to be able to accurately establish risk factors, prospective studies that collect data prior to injury are preferable and prevent confounding due to retrospection, thus offering a more accurate picture.

## 2. Aim of the study

Accordingly, this review focused solely on prospective studies relating to risk factors associated with HSI. The main aim of this study was to establish the existing level and quality of prospective evidence in the sporting arena.

The main objective was to identify any consensus on HSI risk factors and identify gaps in the literature in order to steer future research in this topic.

## 3. Methods

All searches were undertaken between 15 January and 28 February, 2004. To ensure that a comprehensive and definitive literature search was performed the following search strategies were used:

- Online database searching.
- Hand searching.
- Scanning reference lists (snowballing).
- Contacting external sources.

### 3.1. Databases

Seven online databases (AMED, Cochrane Systematic Review Database, EMBASE, MEDLINE, PEDro, SMART and SPORTDiscuss ) were used to enable a comprehensive search covering physiotherapy and sports arenas. Each database was searched independently by two researchers in order to eliminate error, ensure repeatability and increase internal validity (Hek, 1996). Consensus was then reached within the research group using the agreed inclusion/exclusion criteria.

### 3.2. Hand searching

A hand search was undertaken of 24 journals (Table 1) to ensure that current, relevant articles were not missed.

Table 1
Hand searched journals

| |
|---|
| American Journal of Sports Medicine |
| Archives of Physical Medicine and Rehabilitation |
| Australian Journal of Physiotherapy |
| Australian Journal of Science and Medicine in Sport |
| British Journal of Sports Medicine |
| Clinical Journal of Sports Medicine |
| Clinical Rehabilitation |
| Clinics in Sports Medicine |
| Exercise and Sport Science Reviews (electronic) |
| Journal of the Chartered Society of Physiotherapy |
| Journal of Orthopaedics and Sports Physical Therapy |
| Journal of Science and Medicine in Sport |
| Journal of Sports Medicine and Physical Fitness |
| Journal of Sport Rehabilitation |
| Journal of Sports Sciences |
| Medicine and Science in Sports and Exercise |
| Physical Therapy |
| Physical Therapy in Sport |
| Physiotherapy |
| Physiotherapy Canada |
| Physiotherapy Frontline |
| Physiotherapy Research International |
| Physiotherapy Theory and Practice |
| South African Journal of Physiotherapy |

The journal titles were chosen jointly from the Chartered Society of Physiotherapy (2004) list of core articles for physiotherapists and from an article by Bohannon (1999) in Physiotherapy that identified 47 core journals for use by physiotherapists.

### 3.3. Snowballing

Reference lists from all relevant articles were scanned to identify additional papers relevant to the literature search. This produced an additional seven papers for review.

### 3.4. Contacting external sources

Three key authors in the field were contacted regarding any further information that may be relevant to this study.

### 3.5. Keywords

Four 'concepts' were used to describe the different aspects of the study. To ensure that all relevant articles were obtained, a number of key words were used for each concept. Where appropriate, Key words were truncated with $ so that any possible word endings were included (Briddon, 2002). The key words were used to search the core databases of; AMED, EMBASE, Medline and SPORTDiscuss. The CDSR, PEDro and SMART databases use a different format and therefore were searched using a basic search strategy only. The key and truncated key words used were; causation (caus$), predisposing (pred$), prospective studies, risk factors, hamstring($), injury (injur$), tear ($) pull ($), trauma ($), strain ($), sport ($) and exercise

### 3.6. Inclusion and exclusion criteria

Inclusion and exclusion criteria had been agreed prior to the review in order to prevent selection bias when obtaining articles. Once all articles had been retrieved, inclusion and exclusion criteria were applied to ensure that articles were relevant to the study. Table 2 shows the criteria and justification for their use.

### 3.7. Critical appraisal tool

The Critical Appraisal Skills Programme (CASP) tool (2004) was used as a provisional measure to assess the relevance of the articles and eliminate inappropriate papers. Once the final papers had been confirmed, the Parry (1987) guidelines were used for the review as they can be applied to a mix of papers of different design. Two researchers reviewed each paper to increase the internal validity of this study.

## 4. Results

A summary of the main characteristics of the papers reviewed is shown in Table 3. Two of the studies assessed whether interventions, namely thermal pants and pre-season muscle strengthening exercises affected the incidence of HSIs (Upton et al., 1996; Askling et al., 2003). Both studies supported a positive benefit for the two interventions. The other five studies attempted to identify predictor or risk factors for HSI. In two studies (Bennell et al., 1998, Bennell, Tully, & Harvey, 1999), the predictive factors of isokinetic strength and toe touch, were not significantly associated with future HSI. On the other hand Orchard et al. (1997) demonstrated a positive relationship between hamstring muscle weakness and future injury. Cameron, Adams, and Maher (2003) contradicted this finding but did show that motor control and thigh strength differences were positive predictors of HSI. Finally Verrall et al. (2001) attempted to identify clinical risk factors outside of muscle strength and reported significant odds ratios for increasing age, previous history of posterior thigh and knee injury and Aboriginal ancestry. Additionally there was a significant difference in the number of subjects with injuries who had a previous history of groin injury. Previous back injury, height and weight had no influence on the incidence of HSI.

Table 2
Inclusion and exclusion criteria

| Inclusion | Exclusion | Justification |
|---|---|---|
| Prospective studies | Retrospective studies | Retrospective studies can confound cause and effect. NB: There is likely to be some cross-over where 'prospective' studies look at a history of previous injury and thus exhibit 'retrospective' elements. Such studies will have to be carefully considered during the preliminary phase of the evaluation process |
| Sports-related hamstring injuries | Non-sport related hamstring injuries | This review is specifically focused on hamstring injuries in sport |
| English language | Foreign language | Time and resource constraints for translation |
| Professional athletes | Non-professional athletes | The majority of research has been focused on professional sports |
| Primary sources and well-referenced secondary sources | Inadequately referenced secondary sources | Valid judgements are based on primary literature (Domholdt, 2000). References from secondary studies can be used to access relevant primary sources and background information |
| Studies aimed specifically at hamstring injury | General, non-specific studies into musculoskeletal injury | Hamstring injuries are the focus of this study |
| Human subjects | Animal subjects | Findings from animal subjects cannot be reliably transferred to humans |

## 5. Discussion

Due to the heterogeneous nature of the final seven papers to be reviewed, common themes were identified; muscle strength and imbalance, muscle control, range of movement/flexibility, previous injury, anthropometric factors, and muscle fatigue.

### *5.1. Muscle strength and imbalance*

Hamstring muscle weakness has been one of the most commonly proposed risk factors associated with hamstring injury (Burkett, 1970; Agre, 1985). It is suggested that the reduced strength of the hamstrings may produce insufficient force to counteract the quadriceps muscles during knee extension of the swing phase (Agre, 1985). Given this mechanism of injury, it is further postulated that an imbalance of muscle strength between the thigh muscles may also predispose to injury (Burkett, 1970); these factors have been considered together.

Orchard et al. (1997) found hamstring muscle weakness to have a significant association with subsequent HSI, both in absolute values and in hamstrings-to-quadriceps muscle ratio. No such association in absolute values has been found in any of the other studies, although Cameron et al. (2003) concur that hamstrings-to-quadriceps strength was shown to be significant, however this was found to relate to increased quadriceps strength rather than decreased hamstrings strength. This may suggest that where the hamstrings are unable to resist an excessive increase in quadriceps force development they would be at risk of injury. If further conclusive evidence of this assertion were found, it would have significant implications in the practical setting. Current training regimens designed to target hamstring muscle weakness may involve increasing lower limb strength generally and may inadvertently put hamstrings at a greater risk by inducing excessive quadriceps strength (Cameron et al., 2003).

Traditionally, thigh muscle strength has been assessed concentrically; however, for the assessment of muscle imbalance, it would seem more appropriate to replicate the proposed mechanism of injury by analysis of eccentric hamstring strength in relation to concentric quadriceps strength. Such a study was undertaken by Bennell et al. (1998) but no significant differences were found between the injured and non-injured players for any of the variables of muscle strength or imbalance.

A number of differences between the studies may explain these conflicting findings. Cohort size is widely variable (see Table 3); the considerably larger sample size of the Bennell et al. (1998) study increases its rigour and internal validity, thus findings are likely to be more reliable. The sample groups themselves also vary; while all three studies here involved ARF players, Orchard et al. (1997) and Cameron et al. (2003) focussed solely on elite players, whereas Bennell et al. (1998) selected players from a range of professional and 'high level' amateur league teams, thus findings may not be directly comparable. This has further implications on the

Table 3
Summary of selected papers

| Study | Main aim | Method | Sport | Sample size | No. of athletes injured[a] | H–S strength | H–S flexibility | Previous injury | Additional risk factors | Stats approach |
|---|---|---|---|---|---|---|---|---|---|---|
| Askling et al. (2003) | To evaluate effect of pre-season strength training (emphasising eccentric overload) on HSI | Experimental | Soccer | Control:15 | 10 (66.6%) | + | – | + | NA | Univariate |
| | | | | Training:15 | 3 (20%) | | | – | | |
| Cameron et al. (2003) | To investigate motor control & strength as predictors of HSI | Observational Cohort S | ARF | 20 | 6 (30%) | – | NA | – | Motor control (+) H/Q strength ratio (+) Quads strength (+) | Univariate |
| Verrall et al. (2001) | Examiner/ship b/w anthropometric & clinical variables with HSI (Δ with MRI) | Observational cohort study | ARF | 114 | 26 (23%) | NA | NA | + | Age, height, weight, race, PHI: knee, groin, back | Univariate |
| Bennell et al. (1999) | Evaluate relationship of hamstring & lumbar spine flexibility to HIS | Observational cohort study | ARF | 67 | 8 (11.9%) | NA | – | NA | Lumbar spine flexibility (–) | Univariate |
| Bennell et al. (1998) | Investigate isokinetic strength testing as a predictor of HIS | Observational cohort study | ARF | 102 | 12 (12%) | – | NA | + | HS to opposite HS ratio (–), H/Q strength ratio (–) | Univariate |
| Orchard et al. (1997) | Identify pre-season predictors of HSI—focusing on isokinetic strength variables | Observational cohort study | ARF | 37 | 6 (16%) | + | – | – | HS to opposite HS ratio (+), H/Q strength ratio (+) Age, height, weight etc. | Uni- & multivariate |
| Upton et al. (1996)[a] | Determine whether thermal pants reduce risk of recurrent HIS | Quasi-experimental | RUGBY | Group 1:5<br>Group 2:17<br>Group 3:22<br>Wearing<br>Non-wearing | 8<br>24<br><br>10<br>18 | NA | NA | NA | Thermal pants (–) | Univariate |

*Key*: + Significant association; – No significant association; NA Not applicable; HSI Hamstring injury; ARF Australian rules football.
[a]Upton et al. (1996) do not provide data regarding the number of individual athletes injured—they only provide figures for the total number of injuries (i.e. including multiple injuries per athlete).

generalisation of such studies to the wider population and this must be considered when interpreting data.

Neither clinicians nor players were blinded to the preseason tests in the Orchard et al. (1997) study thus bias cannot be eliminated and may confound results.

There continues to be debate regarding the appropriate speed at which peak torque should be measured. Orchard et al. (1997) assessed peak torque at 60, 180 and 300°/s; hamstrings-to-quadriceps strength ratio was found to be lower at 60°/s and it is proposed that this may accentuate the presence of ratio deficits, giving a more accurate indication of HSI risk with regards this variable. All other studies assess peak torque at 60°/s but it is suggested that a speed of 300°/s may be more representative of the typical speed of muscle contraction during sports (Bennell et al., 1998). Further analysis of appropriate speeds for specific variables is required.

A pre-season preventative strength training programme emphasising eccentric hamstring overload was undertaken in premier league Swedish soccer players by Askling et al. (2003). While those following the intervention programme subsequently showed a significantly lower rate of HSI (20%) than the control group (67%), no direct correlation was found between preseason strength or speed measurements and subsequent injury. Furthermore injury rates appear particularly high in this study relative to comparative studies, even in the intervention group. More comprehensive anthropometric measures may shed light on other factors relating to the injuries.

### 5.2. Muscle control

Considering the composite nature of the interaction of the thigh muscles during activities of the lower limb, it would seem logical that poor neuromuscular control of any part of the thigh muscle complex may predispose to HSI (Agre, 1985; Devlin, 2000; Woods et al., 2004), however there are very few studies investigating it in this particular population. Proprioception, i.e. both afferent and efferent information for the whole limb, was tested by Cameron et al. (2003) by devising a 'movement discrimination' (MD) test; poor MD ability was found to have a significant association with subsequent HSI, however the validity of the test in the sporting context is questionable as the test design challenged only one leg at a time with no consideration of the influence of activity in the opposite limb or the limb speeds associated with activities such as sprinting. Altered neuromuscular control has been assigned to a number of factors, namely; lack of proper warm-up, poor training and muscle fatigue where neural activity patterns change (Agre, 1985). Other factors may also impact upon the nervous system, for instance neural tension due to lack of flexibility or a protective reflex mechanism following injury (Bennell, Tully & Harvey, 1999).

### 5.3. ROM/flexibility

Muscle flexibility is said to reflect the muscle's ability to absorb forces, particularly at the end of range where the muscle becomes actively insufficient and the passive non-contractile component must increase its role (Bennell et al., 1998). Previous evidence seems unable to establish whether decreased muscle flexibility is a potential risk factor for injury, or simply just a consequence of it (Drezner, 2003).

To-date, no gold standard for the measurement of flexibility has been established, although it is widely accepted that hamstring range of movement (ROM) represents muscle flexibility (Devlin, 2000). Indeed, of the studies that investigated muscle flexibility, all of them assessed ROM as the measure of flexibility; however, different methods were used for this.

It is claimed that accurate measurement of hamstring length requires stabilisation at the hip and lumbar spine and tests such as the sit-and-reach test (used by Orchard et al., 1997), the straight leg raise (used by Askling et al., 2003) and the toe-touch test (used by Bennell et al., 1999) are inaccurate (Devlin, 2000). None of these studies found any association between decreased ROM and subsequent injury.

Bennell et al. (1999) investigated the lumbo-femoral relationship in the toe-touch test, i.e. rather than limiting movement at the spine, pelvis and hip, discrete measurement of movement at these points was recorded and analysed in relation to subsequent injury. No significant association was found, however research suggests that the greatest alteration in the lumbo-femoral relationship occurs in the first third of the toe-touch test rather than at the end position where the measurement was taken (Van Wingerden, Vleeming, Stam, & Soeckart, 1995). Further analysis of the lumbo-femoral ratio throughout range would help identify any association.

The measure of ROM alone to represent muscle flexibility may be insufficient. It has been suggested that damage to the muscle may not only occur when the muscle complex is at its maximal length but also during early stance phase where the hamstrings are working concentrically (Orchard et al., 1997). A test of muscle flexibility in the mid range may be more appropriate (Cameron et al., 2003). No conclusions can be drawn regarding the most appropriate technique for the assessment of flexibility.

A lack of neural extensibility is likely to decrease ROM (Agre, 1985) and therefore the slump test should be used alongside ROM tests to identify exactly which structure is limiting movement (Cameron et al., 2003).

Warm-up technique or how warm the player was prior to injury may impact on muscle flexibility (Bennell et al., 1999). Upton et al. (1996) investigated this theory by testing the use of thermal pants in rugby players.

While the authors claim to have proven their efficacy in HSI prevention the results clearly show that there was no significant difference between the group who never wore the pants and those who wore them all the time. The small sample size may have prevented statistical significance being reached yet it is apparent that more conclusive evidence is required. It should be noted that this study was undertaken by the manufacturers of the product and there would therefore be some gain in proving their use.

### 5.4. Previous injury

Previous hamstring injury is the most commonly postulated risk factor for further injury (Agre, 1985). Verrall et al. (2001) found that players with a history of HSI were almost five times more susceptible to subsequent injury than those who had not. Previous injury was found to be a significant risk factor independent of any other variables such as muscle strength or muscle imbalance (Bennell et al., 1998). This may suggest either that the rehabilitation of the previous injury had been inadequate or that risk factors for the original injury were still operating. A greater understanding of the specific cause of the initial injury would help in comprising an adequate rehabilitation programme designed for the individual where the underlying problem is addressed and preventative treatment strategies can be implemented to avoid recurrent hamstring strain.

A history of other injuries may also be related. Verrall et al. (2001) found previous knee injury to be a significant factor in subsequent HSI, and previous groin injury almost reached significance. It has been suggested that previous knee injury could alter movement at the superior tibio-fibular joint; with its insertion into the head of the fibula, altered biomechanics of the biceps femoris may result (Woods et al., 2004). Such factors could be prevented from confounding studies by the exclusion of players with previous such injury.

### 5.5. Anthropometric factors

To date, very little consideration has been given to risk factors specific to the individual such as anthropometric measures and anatomical variations (Devlin, 2000). Verrall et al. (2001) found greater subsequent injury in older players, yet the most recent audit of HSI in professional soccer players showed the younger age group to be more susceptible; it is suggested that those with a shorter training history de-condition more quickly and are therefore at greater risk of HSI (Woods et al., 2004).

Interestingly, Verrall et al. (2001) also found that players of Aboriginal descent sustained a significantly higher rate of injuries. Described as the 'fastest and most exciting players', they surmise that such may have a higher proportion of type II fibres within the muscle, predisposing them to injury. It has been suggested that players of Afro-Caribbean origin may also have an increased predisposition to HSI due to an increased anterior tilt of the pelvis (Woods et al., 2004). Further recording and investigation of other anthropometric measures should be undertaken.

### 5.6. Muscle fatigue

Muscle fatigue was not investigated in any of the articles reviewed here, however a recent audit by the English Football Association found that almost half of the injuries encountered during matches occurred in the last third of the first and second halves of the match; hamstring muscle fatigue is implicated in this (Woods et al., 2004). Muscle fatigue may link in with a number of other systems, for instance, it is thought to be detrimental to the neural system, specifically to the dual innervation of the two heads of biceps femoris; mistimed contraction of biceps femoris resulting in a reduced ability to generate sufficient force may increase risk of HSI (Agre, 1985). Other factors related to muscle fatigue may be poor running style, poor training and nutritional deficits (Burkett, 1970; Devlin, 2000; Drezner, 2003).

## 6. Overall limitations of the studies

While a number of factors which may predispose to HSI have been investigated in these papers, differences in study design and methodology make it difficult to draw comparisons between studies. Cohort size has been hugely variable and large cohorts are needed in future studies to verify results. Bahr and Holme (2003) claim that a sample of 20 to 50 is required to test risk factors that have a strong association but for smaller associations as may occur where more than one risk factor is acting, a sample of 200 is required. The reader is directed to the paper on sample size estimation by Batterham and Atkinson (2005) for further information.

Variable sample group may also prevent comparisons being made; for instance it has been shown that HSI is more common amongst elite players than in the lower leagues for both soccer (Woods et al., 2004) and ARF (Orchard et al., 1997). The generalisation of any given study to the wider sporting arena should be carefully considered.

The definition of HSI itself has been variable. Not all the studies verified HSI with a diagnostic test such as ultrasound or magnetic resonance imaging (MRI). Verrall et al. (2001) found that 6 of the 32 injured players had not sustained a HSI as verified by MRI scan. These 6 were said to have 'referred pain posterior thigh injury'. Where diagnostic tests are not used, differentiation between referred pain injuries and HSI cannot be made and risk factors for the two may well be different (Devlin, 2000). Further use of diagnostic tests should be considered for future research.

It would seem that the evidence remains conflicting as no single variable has proved to be consistently significant, suggesting that the cause of HSI is likely to be multi-factorial. Bahr and Holme (2003) claim that injury results from a complex interaction of multiple risk factors and events, many of which are yet to be identified. The Meeuwisse model of injury states that both an internal 'predisposing' risk factor and an 'external, enabling factor' must be present for injury to occur. Further to this it is suggested that an 'inciting event' (injury mechanism) is required in order to cause HSI (Bahr and Holme, 2003), where the 'inciting event' involves not only the biomechanical factors, but also all events leading up to the injury point, such as playing position on the pitch, training regime, match schedule.

Considering the interdependent relationship of risk factors as suggested in this model and as demonstrated in part by the reviewed literature, further studies must investigate the relationship between factors in order to discover patterns of injury. For instance, specific information regarding the lead up to injury such as the speed and phase of running (accelerating or decelerating), direction (backwards, forwards, sideways) and player position on the pitch, may be helpful in identifying risk factors (Woods et al., 2004); these were not recorded in any of the studies. External factors such as different training regimes, different terrain or climate may impact on results and should be further investigated (Devlin, 2000).

Furthermore, statistical analysis should reflect the likely multi-factorial nature of HSI by using multivariate tests that investigate the association of a number of factors acting together (Bahr & Holme, 2003).

## 7. Limitations of this literature review

An extremely thorough search strategy was used in this study; however limitations exist due to the nature of the study. Large cohort studies tend to investigate a number of musculoskeletal injuries rather than specifically HSI, but these were excluded from this study and as such this is a major limitation to this work. Also, non-English papers were excluded, limiting the range of papers available for evaluation. It can be difficult to gain access to papers investigating professional sports cohorts and therefore this is unlikely to be a truly comprehensive literature review of evidence available; a broader study incorporating amateur and college teams may have been appropriate.

## 8. Conclusion

This literature review has identified a number of potential risk factors to HSI, namely; hamstring muscle weakness and thigh muscle imbalance, poor neuromuscular control, decreased muscle flexibility, previous hamstring injury, other previous injury and anthropometric factors, however, no single variable has been found to have a consistent association with HSI and it is clear that a paucity of prospective studies into the causation of such injuries exists. Further prospective studies are required involving larger cohorts and looking at a wider range of variables as suggested above to reflect the multi-factorial nature of HSI. Statistical analyses should also reflect this by using multivariate tests that measure the effects of more than one variable at a time. Such evidence would help identify those at risk of HSI and aid in the development of both preventative and rehabilitative treatment programmes for the management of HSI in sports. Professional sports clubs in particular need a multiple base-line of measures as suggested, for each player and then interpret fully the outcome data, if a sensible approach to prevention and rehabilitation is to be achieved.

## References

Agre, J. C. (1985). Hamstring injuries: Proposed aetiological factors, prevention, and treatment. *Sports Medicine*, *2*, 21–33.

Askling, C., Karlsson, J., & Thorstensson, A. (2003). Hamstring injury occurrence in elite soccer players after strength training with eccentric overload. *Scandinavian Journal of Medicine and Science in Sports*, *13*, 244–250.

Bahr, R., & Holme, I. (2003). Risk factors for sports injuries—a methodological approach. *British Journal of Sports Medicine*, *37*, 384–392.

Batterham, A. M., & Atkinson, G. (2005). How big does my sample size need to be? A primer on the murky world of sample size estimation. *Physical Therapy in Sport*, *6*(3), 153–163.

Bennell, K., Tully, E., & Harvey, N. (1999). Does the toe-touch test predict hamstring injury in Australian Rules footballers? *Australian Journal of Physiotherapy*, *45*, 103–109.

Bennell, K., Wajswelner, H., Lew, P., Schall-Riaucour, A., Leslie, S., Plant, D., & Cirone, J. (1998). Isokinetic strength testing does not predict hamstring injury in Australian Rules footballers. *British Journal of Sports Medicine*, *32*, 309–314.

Bohannon, R. (1999). Core journals of physiotherapy. *Physiotherapy*, *85*(6), 317–321.

Briddon, J. (2002). Making the best use of library resources: Health and social care. Available from: http://www.uwe.ac.uk/library—accessed 20 February 2004.

Burkett, L. N. (1970). Causative factors in hamstring strains. *Medicine and Science in Sports and Exercise*, *2*, 39–42.

Cameron, M., Adams, R., & Maher, C. (2003). Motor control and strength as predictors of hamstring injury in elite players of Australian football. *Physical Therapy in Sport*, *4*, 159–166.

Chartered Society of Physiotherapy. (2004). Core list of databases. Available from: www.csp.org.uk/libraryandinformation/library/physiotherapycollections/corelist.cfm#2 (accessed: 25 February 2004).

Critical Appraisal Skills Programme (CASP) appraisal tool. (2004). http://www.phru.nhs.uk/casp/casp.htm—accessed 2 January 2005.

Devlin, L. (2000). Recurrent posterior thigh symptoms detrimental to performance in rugby union: Predisposing factors. *Sports Medicine*, *29*(4), 273–287.

Domholdt, E. (2000). *Physical therapy: Research principles and applications* (2nd ed.). London: WB Saunders Co Publications.

Drezner, J. A. (2003). Practical management: Hamstring muscle injuries. *Clinical Journal of Sport Medicine*, *13*, 48–52.

Hawkins, R. D., Hulse, M. A., Wilkinson, C., Hodson, A., & Gibson, M. (2001). The association football medical research programme: An audit of injuries in professional football. *British Journal of Sports Medicine*, *35*, 43–47.

Hek, G. (1996). *Guidelines on conducting a critical research evaluation*. London: BMJ Publishing Group.

Orchard, J., Marsden, J., Lord, S., & Garlick, D. (1997). Preseason hamstring muscle weakness associated with hamstring muscle injury in Australian footballers. *The American Journal of Sports Medicine*, *25*(1), 81–85.

Orchard, J., & Seward, H. (2002). Epidemiology of injuries in the Australian Football League, seasons 1997–2000. *British Journal of Sports Medicine*, *36*, 39–45.

Parry, A. (1987). Guidelines to appraising research papers in journals. *Physiotherapy*, *73*(7), 375–378.

Tortora, G. J., & Grabowski, S. R. (2003). *Principles of anatomy and physiology* (10th ed.). New York: Wiley.

Upton, P. A. H., Noakes, T. D., & Juritz, J. M. (1996). Thermal pants may reduce the risk of recurrent hamstring injuries in rugby players. *British Journal of Sports Medicine*, *30*, 57–60.

Van Wingerden, J. P., Vleeming, A., Stam, H. J., & Soeckart, R. (1995). Interaction of spine and legs: Influence of hamstring tension on lumbo-pelvic rhythm. In A. Vleeming, V. Mooney, C. Snijders, & T. Dorman (Eds.). The integrated function of the lumbar spine and sacroiliac joints. Second interdisciplinary World Congress on low back pain (pp. 111–121). San Diego.

Verrall, G. M., Slavotinek, J. P., Barnes, P. G., Fon, G. T., & Spriggins, A. J. (2001). Clinical risk factors for hamstring muscle strain injury: A prospective study with correlation of injury by magnetic resonance imaging. *British Journal of Sports Medicine*, *35*, 435–440.

Woods, C., Hawkins, R. D., Hulse, M., & Hodson, A. (2002). The football association medical research programme: An audit of injuries in professional football—analysis of preseason injuries. *British Journal of Sports Medicine*, *36*, 436–441.

Woods, C., Hawkins, R. D., Maltby, S., Hulse, M., Thomas, A., & Hodson, A. (2004). The Football Association Medical Research Programme: An audit of injuries in professional football—analysis of hamstring injuries. *British Journal of Sports Medicine*, *38*, 36–41.