Preventing hamstring injuries - Part 1: Is there really an eccentric action of the hamstrings in high speed running and does it matter?

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Hamstrings | Injuries | Eccentric | High speed running

Headline

Hamstring injuries remain a major burden in sport (1) despite enormous research efforts and the development of apparently effective prevention (2,3) and rehabilitation practices.(4) Interventions that work in amateur and lower levels of professional sport may not be fully implemented in the more crowded training and playing schedules of elite sport (5) and perhaps they work only in less fit athletes or their benefits are ‘drowned out’ by other training methods? We suggest that belief systems and philosophies shared widely by expert coaches also reduce adoption of some evidence-based practices.

van Hooren and Bosch recently argued that isometric conditioning may be more effective at reducing hamstring injuries and more readily programmed into busy competition schedules than eccentric exercise.(6, 7) Here, we critique these arguments and offer some insights into an eccentric strength and sprint-oriented injury prevention program that has been employed to good effect in the English Premier League. We do not claim that anecdotal evidence is in any way definitive. Nor do we claim that isometric training doesn’t work or that eccentric hamstring conditioning is the only effective means of prevention. Instead we argue that recommendations to employ an isometric approach instead of an eccentric one are premature.

Do the hamstrings act isometrically or eccentrically in late swing?

The argument for isometric hamstring conditioning is based, to a significant extent, on the authors’ proposal that the contractile elements (fascicles) of these muscles act isometrically, rather than eccentrically in the late swing phase of sprint gait.(6) Current biomechanical models suggest that hamstring fascicles actively lengthen in late swing (8) but van Hooren and Bosch argue that stretch in the series elastic element (aponeuroses and tendons) of the hamstrings is underestimated in these models and that active fascicle lengthening is therefore over-estimated.(6) As modelling is based partly on assumptions, it is prone to error and we remain open-minded regarding this aspect of the authors’ argument. However, the likely existence of some error does not prove that hamstring fascicles behave isometrically in sprinting.

Unfortunately, human hamstrings defy direct observation in sprinting, partly because ultrasound probes don’t provide clear images of their fascicles during violent movement of the lower limbs.(9) So instead, the authors describe studies of quadriiceps (eg. 10) and plantar-flexor (eg. 11) behaviour during small and large amplitude stretch-shorten cycles of jumping. Ultrasound imaging of fascicle and aponeurosis behaviour in these muscles is effective but, as the authors suggest, inferences from vastus lateralis and gastrocnemius research to hamstring behaviour must be cautious ones. Differences in stiffness between the Achilles, patella and hamstring tendons along with disparities in pennation angles, gearing ratios and fascicle to muscle-tendon unit length ratios all increase the potential for these muscles to exhibit diverse behaviours. Furthermore, the movement speeds in jumping are nowhere near those of sprinting.

In small amplitude stretch-shorten cycles, fascicles of the medial gastrocnemius are quasi-isometric when active, with the lengthening and recoil of the muscle-tendon units almost entirely limited to the aponeuroses and tendons (Figure 1).(11) So jumps of this amplitude essentially involve bouncing off our in-built ‘springs’ and are energy efficient as a consequence. Large amplitude stretch-shorten cycles involve greater ranges of motion, as observed when performing jumps with bigger counter-movements (eg a deeper knee bend) and length changes occur in both fascicles and the series elastic elements of the vastus lateralis in these circumstances (Figure 1).(10) However, vastus lateralis fascicles lengthen progressively less as stretch-shorten cycles increase in intensity.

In large amplitude SSCCs the CE remains at virtually constant length while active and the lengthening (a → b) and subsequent recoil (b → a) occurs almost entirely within the SEE. In large amplitude SSCCs, the CE and SEE both lengthen (a → d) until the CE becomes isometric and the remaining shortening is confined to the SEE (d → e). Shortening initially involves recoil of the SEE (e → d) after which both the CE and SEE shorten (d → c).

Fig. 1. Representations of the contractile element (CE), series (SEE) and parallel elastic elements (PEE) and pennation angle (Θ) during stretch shorten cycles (SSCs).
(jump height)(10) and the author’s point out that a continuation of this trend may eventually see the fascicles remain isometric.(6) They also argue that contractile elements lengthen in these large amplitude movements because the forces are ‘too high’ to resist and they thereby characterise this lengthening as a deviation from optimal behaviour. However, an alternative interpretation is that contractile elements simply have to lengthen when large ranges of motion are utilised. Furthermore, no evidence is presented that human hamstring fascicles behave isometrically in sprinting and these claims currently amount to well-reasoned speculation.(6)

Having argued that hamstring fascicles are typically isometric in the late swing of sprinting, van Hooren and Bosch (6) then suggest that aberrant fascicle lengthening may occasionally occur and that this may cause hamstring strain injury. They write that poorly coordinated lumbopelvic motion may occasionally force the hamstrings to actively lengthen. This is an important acknowledgement because strain injury is unlikely to occur during isometric contractions.(12) However, we suggest this is also a major flaw in the authors’ argument and that a rationale for eccentric training fits perfectly into this gap. We contend that the damage resistance rationale for eccentric training (13) holds whether active lengthening occurs in every stride or only on rare occasions during sprinting. As a consequence, the typical contraction mode of hamstring fascicles in sprinting may matter less than the authors suggest.

Is ‘damage resistance’ a function of training intensity or contraction mode?

Eccentric training may exert at least some of its benefits via an increase in in-series sarcomeres and the lengthening of hamstring fascicles.(13, 14, 15) Accordingly, hamstrings with longer fascicles appear less prone to injury than those with shorter fascicles.(16) Possible benefits to sarcomeres experience less strain and are less likely to be over-extended. While van Hooren and Bosch (6) contend that the effect of contraction mode on fascicle length is not clear, their argument is made mostly on the basis of quadriceps studies, which are inconsistent. However, as of November 2017, eccentric hamstring training has been shown to lengthen hamstring fascicles in 9 of 10 published training studies while 2 of 2 concentric training studies have been shown to shorten them.(17)

The authors also suggest that any high intensity hamstring training may reduce injury rates, regardless of contraction mode.(6) For all we know this may be true, but this speculative argument seems to ignore the force-velocity relationship of skeletal muscle. Isometric contractions simply can’t be performed at the forces observed in maximal eccentric-only or eccentrically-biased resistance training, so if intensity matters, eccentric actions are the means to maximise it. Nevertheless, there is evidence that contraction mode plays an important role in skeletal muscle damage resistance independent of exercise intensity.(13) For example, the original rat studies that compared eccentric and concentric training of vastus intermedius muscles employed decline and incline treadmill running at trotting speeds for 15 to 35 minutes per session over 5 days.

The low intensity eccentric actions in decline running resulted in the development of more in-series sarcomeres than did the concentric actions performed during incline running.(13, 18) In one of these studies, the extent of force loss and the shift in the force-length relationships caused by 20 maximal (electrically stimulated) eccentric actions was markedly smaller in eccentrically trained muscles and this is interpreted as enhanced damage resistance that may also help protect against strain injury.(13) In humans, there is also evidence that mild eccentric training (downhill walking) results in protection from eccentrically-induced muscle damage,(19) while mild concentric training increases the susceptibility to muscle damage.(20) Timmins and colleagues (15) have also shown that knee flexor training with maximal concentric actions results in rapid shortening of hamstring fascicles while eccentric training lengthens them, despite long muscle lengths being reached in both. As far as we are aware, there is no published research on the effects of isometric training on hamstring fascicle length. However, Pollard and colleagues (21) have recently found that high intensity training with the razor curl, a quasi-isometric hamstring exercise, does not increase biceps femoris fascicle lengths while the high intensity Nordic hamstring exercise does (unpublished observations). These collective findings suggest that eccentric actions induce more favourable architectural adaptations than concentric and isometric ones, regardless of contraction intensity, although more work on isometric training needs to be done to confirm this.

Impact on running coordination?

Departing from their contraction mode argument, van Hooren and Bosch propose that the Nordic hamstring exercise does not alter hip and trunk muscle coordination in running.(7) However, it has never been argued that this exercise alters running technique. It might also be argued that the authors’ suggested alternatives, many of which are exercises performed from a Roman chair at neutral hip angles,(7) are also disparate from running in terms of movement pattern, velocity and posture and that none of these exercises are particularly likely to directly influence sprint technique. Nevertheless, the argument for employing hip extensor exercises for hamstring injury prevention is one with which we entirely agree.(14,17)

Scheduling eccentric hamstring conditioning in elite sport

Van Hooren and Bosch contend that because it causes less soreness, isometric training will fit better than eccentric exercises into the crowded competition schedules in elite sport.(7)
This congestion is arguably highest in elite European soccer where teams may occasionally play as many as eight matches in 21 days. However, the well-documented repeated bout effect ensures that supramaximal eccentric training can be performed with limited soreness after the initial 2-3 weeks (2, 14) and one of us (SM) has experience implementing a hamstring injury prevention program in the English Premier League with a degree of success. We therefore believe that careful planning can overcome these issues.

The incorporation of eccentric training into Leicester City FC’s hamstring injury prevention philosophy was predominately driven by the growing evidence in favour of this approach (2, 3). Due to the revolving door nature of a multi-national EPL squad, the club is acutely aware of the associated communication barriers and differing training histories clubs may experience with their athletes. As such, the strength development culture has been based on avoiding technically demanding exercises (e.g., Olympic lifts) and thereby enabling players to push high loads for few repetitions. High intensity low volume eccentric training of the hamstrings fits well into this philosophy which is complemented by a broader, multimodal approach of weekly load management and high speed running exposure.

While muscle soreness often limits the application of eccentric training, perseverance allows soreness to diminish over time. Players are encouraged to view soreness as an adaptation rather than a concern, and to trust staff to protect them via appropriate manipulation of loading strategies. Timing of eccentric work in the training week therefore becomes crucial. Eccentrics can be safely administered following adequate recovery post-match, but must also permit a suitable period for recovery ahead of the next game. At Leicester City eccentric training has traditionally been placed three days post-match day (MD+3) for a one game week, but this approach must be flexible to accommodate change (Figure 2).

Where periods of high fixture congestion occur, the focus turns to maximising the windows of opportunity for players who don’t play or play reduced minutes from the substitutes’ bench. For starting players, the focus in this period is solely to recover from the accumulated match day muscle damage in time for the next fixture and eccentric training is not appropriate. Portable training equipment can be used both home and away to achieve this stimulus in the target group after the match. This is complemented by short sessions with a high speed running focus on the pitch.

Leicester City employ knee and hip orientated hamstring exercises. Whilst there is an appreciation of individual muscle activation for the chosen exercises (17) this doesn’t exclusively guide the process as some exercises are favoured for their simplicity. There is a focus on building an appropriate base level of strength via an overload programme in pre-season. Doing so builds eccentric strength levels and presumably evokes favourable architectural adaptations (14, 15) that can be maintained with a relatively low volume of high intensity work throughout the season. In season training typically involves 1-2 sets of 3 repetitions of Nordics, 2 sets of 8 double leg/weighted eccentric slideouts and 2 sets of 6-8 double or single leg dumbbell Romanian deadlifts (Figure 3). The club can objectively track knee-flexor strength but recognises that these low volumes may limit strength improvements. Instead the maximal Nordics are less of a strength training set but more a monitoring/structural training set to offer an eccentric exposure that may maintain favourable fascicle lengths and provide strains to the series elastic element. The added hip and knee volume sets then top up this exposure and help condition the muscle in a less strenuous manner. All exercises are performed after training to work the muscle in a fatigued state. This approach aims to make weak players strong, but making strong players stronger with large external loads isn’t necessarily the priority. The club feels that this approach helps avoid potentially inhibitory levels of soreness that negatively influence compliance.

It should be acknowledged that strong athletes still injure their hamstrings. We suggest high speed running is the most
Table 1. Summary of the major arguments addressed in this paper. These are not exhaustive and the reader is directed towards the van Hooren and Bosch papers for a more detailed argument.

<table>
<thead>
<tr>
<th>The argument for isometrics</th>
<th>The counter-argument</th>
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<tr>
<td>Hamstring fascicles are argued to be isometric in the late-swing of sprinting &amp; isometric strength training is therefore more specific.</td>
<td>All currently published modelling studies show active lengthening in late-swing but these models do involve assumptions. van Hooren and Bosch acknowledge that eccentric actions may occasionally occur inadvertently and cause injury. We suggest that the argument for eccentric training is valid regardless of whether the hamstrings act eccentrically in every stride or only rarely.</td>
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<tr>
<td>The benefit of hamstring injury prevention exercise is determined by contraction intensity more than contraction mode.</td>
<td>Only eccentric actions have significant potential to cause muscle damage at moderate muscle lengths and trigger adaptations that create damage resistance (eg the repeated bout effect).</td>
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<td>The NHE does not improve coordination of hip extensor and trunk muscles the way that other exercises do.</td>
<td>Improved coordination is not the mechanism by which the NHE works. Whether isometric exercises are more specific to running remains to be seen. We agree that hip extensor exercises are important in injury prevention.</td>
</tr>
<tr>
<td>Easier to schedule isometric than eccentric training into crowded training programs because the former causes less delayed soreness.</td>
<td>This is undoubtedly true but only of relevance if isometrics prove effective. It is also possible to program low volumes of eccentric strength training into a crowded training schedule.</td>
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Table 1. Summary of the major arguments addressed in this paper. These are not exhaustive and the reader is directed towards the van Hooren and Bosch papers for a more detailed argument.

Comparing the current evidence for isometric and eccentric hamstring conditioning

van Hooren and Bosch correctly point out that there is no evidence that eccentric conditioning is better than isometric approaches. As far as we are aware, there are no experimental studies examining the effects of isometric hamstring training on injury rates and a large scale (n = 500+) randomised controlled trial comparing these methods would be an ideal test of this argument. We acknowledge that even if isometric approaches prove to be half as effective as eccentric approaches have in the past,(2, 3) they would likely have a greater impact in elite sport as long as their adoption is adequate.(5) For now, however, there is level 1 evidence, including systematic reviews (22) and large scale randomised controlled trials for eccentrics,(2, 3) while the evidence for isometrics remains at level 5 (expert opinion). Indeed, the argument for isometrics is, for now, entirely theoretical. So where does this leave the practitioner who designs training programs? Not all decisions in sport can be evidence-based and not all findings from research fit neatly into the schedules or the beliefs of any given team. We offer insights into how eccentric hamstring conditioning can be accommodated in elite sport despite crowded schedules; however, we also acknowledge that expert opinion has a role in the development of injury prevention strategies. Future research may well provide evidence for isometric approaches to hamstring injury prevention and we suggest that a skillfully programmed combination of knee and hip oriented (14, 17) eccentric, isometric and conventional resistance training approaches may be used, along with high speed running, with likely success in elite sport. Finally, we commend van Hooren and Bosch for publishing a thorough and well-written argument for isometric hamstring conditioning.(6,7) We believe, like Popper, that “the growth of knowledge depends entirely on disagreement” and we hope that our arguments are accepted in this spirit. We also look forward to future scientific exploration of isometric approaches to hamstring injury prevention and enhancing athletic performance.

Acknowledgements

Tony Shield is a shareholder in a company that makes a hamstring strength testing device which measures eccentric and isometric knee flexor strength. The device is impartial to the results of the current debate. Simon Murphy has no conflicts of interest to declare.
References


