London International Consensus and Delphi study on hamstring injuries part 3: rehabilitation, running and return to sport

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ABSTRACT

Hamstring injuries (HSIs) are the most common athletic injury in running and pivoting sports, but despite large amounts of research, injury rates have not declined in the last 2 decades. HSI often recur and many areas are lacking evidence and guidance for optimal rehabilitation. This study aimed to develop an international expert consensus for the management of HSI. A modified Delphi methodology and consensus process was used with an international expert panel, involving two rounds of online questionnaires and an intermediate round involving a consensus meeting. The initial information gathering round questionnaire was sent to 46 international experts, which comprised open-ended questions covering decision-making domains in HSI. Thematic analysis of responses outlined key domains, which were evaluated by a smaller international subgroup (n=15), comprising clinical academic sports medicine physicians, physiotherapists and orthopaedic surgeons in a consensus meeting. After group discussion around each domain, a series of consensus statements were prepared, debated and refined. A round 2 questionnaire was sent to 112 international hamstring experts to vote on these statements and determine level of agreement. Consensus threshold was set a priori at 70%. Expert response rates were 35/46 (76%) (first round), 15/35 (attendees/invitees to meeting day) and 99/112 (88.2%) for final survey round. Statements on rehabilitation reaching consensus centred around: exercise selection and dosage (78.8%–96.3% agreement), impact of the kinetic chain (95%), criteria to progress exercise (73%–92.7%), running and sprinting (83%–100%) in rehabilitation and criteria for return to sport (RTS) (78.3%–98.3%). Benchmarks for flexibility (40%) and strength (66.1%) and adjuncts to rehabilitation (68.9%) did not reach agreement. This consensus panel recommends individualised rehabilitation based on the athlete, sporting demands, involved muscle(s) and injury type and severity (89.8%). Early-stage rehab should avoid high strain loads and rates. Loading is important but with less consensus on optimum progression and dosage. This panel recommends rehabilitation progress based on capacity and symptoms, with pain thresholds dependent on activity, except pain-free criteria supported for sprinting (85.5%). Experts focus on the demands and capacity required for match play when deciding the rehabilitation end goal and timing of RTS (89.8%). The expert panellists in this study followed evidence on aspects of rehabilitation after HSI, suggesting rehabilitation prescription should be individualised, but clarified areas where evidence was lacking. Additional research is required to determine the optimal load dose, timing and criteria for HSI rehabilitation and the monitoring and testing metrics to determine safe rapid progression in rehabilitation and safe RTS. Further research would benefit optimising: prescription of running and sprinting, the application of adjuncts in rehabilitation and treatment of kinetic chain HSI factors.

INTRODUCTION

Hamstring injuries (HSIs) remain the most significant time loss injury in football and high-intensity running sports,[1 2] with large financial, physical and emotional costs. Research on prevention strategies has not been effective in reducing injury incidence and recurrences have remained constant in elite soccer,[3 4] whereas the incidence of other injuries has reduced.[5]

Rehabilitation of HSI has evolved to address inflammation, promote biological healing and emphasise optimal loading throughout the rehabilitation.[6] The individual hamstring muscles have often been treated uniformly as they work in conjunction, but evidence has emerged, demonstrating that they have different functional roles, capabilities and injury mechanisms,[7] based on their anatomy and nerve supply,[8] fibre type composition[9 10] and connective tissue (CT) architecture.[8 11 12] Each muscle may therefore require a different rehabilitation approach,[11 13 14] influencing exercise selection in rehabilitation.[15 16] Evidence has emerged to inform exercise prescription in HSI prevention,[17 18] but exercise selection to inform rehabilitation remains unclear and some consensus reviews ignore exercise completely.[19]

The effects of rehabilitation approaches investigating single exercises are common[20–22] but few studies have examined combined programmes. These exist in football, sprinting,[23–26] general sports[27] and Australian rules football[28]; however, they differ significantly, and few rehabilitation protocols investigate higher grade tendon HSIs requiring longer rehabilitation and time to return to sport (RTS).[29] A 2015 review of rehabilitation

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KEY FINDINGS

- ⇒ Differences in hamstring musculotendinous tissue, muscle anatomy and functional roles should direct the rehabilitation prescription for different muscles and myotendinous tissues after hamstring injury (HSI).
- ⇒ In early-stage rehab, most experts advocate protection of injured tissue from loading at length and elastic loads (ie, high strain and strain rate loads).
- ⇒ In early loading, the types of load/contraction considered appropriate, and the order of their application varied greatly between experts. While experts initially prescribe isometric exercises, there is evidence of less force development with concentric exercise compared with isometric exercise and consequently less connective tissue strain.
- ⇒ Experts considered the key kinetic chain deficits as possible contributing factors to (re)injury.
- ⇒ Adjuncts such as strength training with blood flow restriction are increasingly used to allow earlier strength adaptation but did not achieve global consensus agreement.
- ⇒ Experts use an integrated assessment of symptoms, strength and response to previous loading as criteria for progressing and dosing exercise and deciding on safety to return to running (RTR) and return to sport (RTS). Other criteria such as flexibility and special RTS tests are used less widely.
- ⇒ On criteria related to pain, experts suggest some activities should be pain free through rehabilitation (ie, sprinting) but with other exercise activities, a pain threshold approach can be permitted.
- ⇒ In later loading, experts aim to achieve full outer length strength and eccentric strength as key criteria for RTR and RTS.
- ⇒ In later-stage rehab, experts advocate prescription of running and sprinting as key components of HSI rehabilitation and as key progression criteria for RTS.
- ⇒ Experts focus on the demands and capacity required for competition when deciding the rehabilitation end goal and timing of RTS. Experts monitor and test athletes through rehabilitation and use modalities such as global positioning system to give sports-specific information on loading/running dosages, speed and RTS readiness.

studies was unable to pool the rehabilitation literature due to heterogeneity.[30] Interventions included: strength exercises (lengthened vs shortened),[24 31] progressive agility and trunk stabilisation,[32] progressive running and stretching,[33] static stretching[34] and sacroiliac manipulation.[35] Separated meta-analyses of these studies found that lengthening exercises reduce time to RTS but none of the other types provided superior results. Reinjury rates, when reported, were not significantly different between programmes. These interventions did not follow a clinically reasoned rehabilitation approach. Given this heterogenous small sample (6 studies with around 386 HSI athletes), there is a need for more robust evidence to inform rehabilitation after HSI.

There are guidelines and reviews published on criteria for RTS after HSI,[28 36–41] but these are in lower grade injuries. Criteria tests often do not mimic specific sporting loads or functional demands,[39 40] and do not quantify subsequent reinjury risk.[40] There is a need to determine if and how current criteria are used in practice and if this aligns with the available evidence. There may be a need to develop more specific criteria for RTS that link more closely with hamstring function in specific sports.

The volume of the literature on HSI rehabilitation is increasing, but current rehabilitation practice does not always follow research.[42] Less evidence is available in elite sport athletes. Research contains small sample sizes, and decision-making draws on clinical expertise. While there are significant drivers to achieve a faster more robust RTS, multiple stakeholder interests frequently result in athletes RTS while still vulnerable to reinjury.[43] To more clearly understand current practice, innovation and level of expertise pertaining to HSI rehabilitation in elite sport settings, a qualitative research approach is required to outline assessment and treatment decision-making of global experts whose aim is to achieve the best outcome for their athletes.

The London International Hamstring Injury consensus group was convened in 2020. Our aim was to determine, based on expert consensus, the key aspects in rehabilitation and RTS decision-making in the assessment and treatment of HSIs.

METHODS

Study design

We used a modified Delphi research design, including an international panel of experts, with the aim of reaching a consensus on best practice for decision-making in rehabilitation and RTS after HSI. The Delphi process is a scientific, iterative, multistage process used to achieve expert consensus in a given subject, particularly, where a limited literature is available to guide decision-making.[44 45] It takes into account expert opinion and expert clinical practice.[46] There have been previous Delphi studies in prevention[47] and RTS after HSI,[48 49] but the group sought to obtain expert consensus on best-practice rehabilitation, given current disparate and conflicting approaches.

The methodology followed guidance on Delphi studies[44 50] web survey design[51] (the Checklist for Reporting Results of Internet E-Surveys[51] and the reporting standard for conducting and reporting Delphi studies)[50] to avoid bias and is described below and in online supplemental file 1 and methodology in paper 1 in this series.

Expert panel

An international representative group of multidisciplinary clinicians and researchers were invited to participate, based on their expertise in assessment and management (including rehabilitation and RTS) of HSI. A purposive, heterogeneous representative sample of experts was chosen with a mix of: professional discipline (sport and exercise medicine physicians, physiotherapists, surgeons, sport and exercise scientists/researchers and athletic trainers), international location (or work schedule), gender and sporting discipline, in line with Delphi methodology.[52]

The criteria for expert inclusion were: a high level of expertise assessing, managing, rehabilitating and/or researching HSIs, based on: the number and type of HSI seen per year, years worked with athletes who sustain HSI, willingness to complete the digital survey and or attend the consensus meeting, sufficient level of written and spoken English and/or peer reviewed publication (authorship) in hamstring research. Possible experts were excluded if they had (1) insufficient experience of assessment or management of HSI, (2) insufficient time to fully complete the online survey. Clinicians and non-clinicians were included but asked to answer only those survey questions related to their fields of expertise (see online supplemental methodology). Domains of surgery, postsurgical recovery, diagnosis and classification were also identified and experts were chosen, with sufficient expertise in these combined areas, as well as rehabilitation.

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Coaches and trainers comprised 6% of the experts for the final survey. While they did not all have experience in diagnosis or surgery domains, or early rehabilitation, their expertise in late-stage rehabilitation, running and RTS was sought. Athletes were not included; however, we would acknowledge their voices as vital. Many of our experts have also been athletes and 38% of the final survey expert respondents reported a personal history of HSI, being patients themselves.

Modified Delphi process

The study was undertaken after a review of decision-making aspects of the assessment and management and rehabilitation of HSI. The literature was searched, the evidence discussed and the author team led a review of the evidence presented as a narrative summary to inform the consensus rationale and knowledge gaps. The study comprised two rounds of a purposive digital survey interspersed with a face-to-face meeting round. Each round was modified, based on feedback to achieve a consensus among the international panel of experts. Each Delphi round comprised a digital questionnaire, an analysis and a feedback report.

Round one involved a digital survey, with open-ended questions to a global group of clinicians with expertise in treating HSI. The round one survey (see online supplemental methods appendix 1) aimed to gather information, and understand, from the experts' viewpoint, where are the gaps in the literature evidence and clinical practice in HSI rehabilitation, return to running (RTR), sprinting and RTS. The initial round 1 survey comprised open-ended qualitative information gathering questions. The survey used a digital institution-based software package—Opinio V.7.12 (1998–2020 ObjectPlanet, Oslo, Norway).

The responses from the initial survey were collated and analysed with a thematic and factor analysis[53] (see online supplemental file 1). The expert panel identified four key domains, which included rehabilitation and RTR and RTS. This paper deals with results of rehabilitation and RTS, with previous papers covering classification and surgery. The questions were presented for discussion. All the panel members who completed the survey were invited to the discussion meeting, which comprised a 2-day meeting, alongside an international conference, to allow as many of the participants to join as possible. A nominal group consensus model was followed with a facilitated, structured approach to gather qualitative information, from this group.[54] This approach has been followed in other consensus projects.[55 56] In discussions, facilitators maintained impartiality and ensured balanced discussion to avoid discussions being dominated by the most eminent clinicians/academics ('eminence' bias). They aimed to work toward agreement but not force consensus. Dissenting and outlier views were considered important, representing differences in practice. This approach aimed to avoid 'herding' bias.[57] The key consensus statements were synthesised and refined. The rehabilitation sessions were chaired by the steering committee author related to their area of specialisation—rehabilitation (BMP), RTR/RTS (MG). Statements were gradually refined through a process of facilitated debate until the entire panel were satisfied and on day 2 were put to the group for anonymous electronic voting (see online supplemental appendix 4 for the complete list of statements—rehabilitation, RTS/RTR, classification and surgery).

The consensus steering committee established an a priori criterion threshold of 70%, with ≥70% agreed/yes responses constituting statement acceptance. Overall, 70% has been used successfully by other Delphi studies.[58–60] Statements reaching group consensus were retained, with rehabilitation (11), RTR (8) and RTS (12).

The final Delphi round involved a further online survey to test these statements with this survey to a wider international group of experts who met the previous inclusion/exclusion criteria. The participants voted on the statements with yes, no, uncertain ('forced choice') responses. This made the final survey shorter and less onerous for participants but some further Likert or factor ranking questions determined level of agreement (LOA) (see online supplemental examples methodology).

These experts voted on statements and ranked their key decision-making factors or justifications related to the domain areas found in the round 1 survey. See tables 1–3 for consensus statements, voting results and typical discussion points or areas of disagreement (open-ended questions).

Expert panel for final round

The final survey, with voting on the consensus statements, was split into domain sections—classification, surgery, rehabilitation, RTR/RTS. The expert panel in this survey were asked to complete only the domains (sections of the survey) that were within their field and scope of expertise. The survey responses were evaluated for completeness. Survey responses in each domain were evaluated by two steering group members and any incomplete responses from non-experts in that particular domain were removed from the analysis. Within their expertise areas, panel members were asked to complete sections as carefully as possible and provided with response options such as 'uncertain'. Open-ended boxes after each consensus statement also allowed them to comment, and comments and areas of disagreement were collated and analysed and grouped by theme.

Steering committee

The surveys were designed by two experienced clinical academic physiotherapists, and a professor of orthopaedic surgery, who each have greater than 20 years clinical experience treating HSI and research expertise in HSI, as well as previous experience with Delphi research. A structured, iterative process was undertaken to develop the survey and it was piloted by a mixed group of five sports medicine physicians, five physiotherapists and five orthopaedic surgeons, and the survey was further refined based on their feedback. The expert panel were approached by email located from publicly available correspondence information on organisational web sites or peer reviewed journal articles. Information was provided prior to participation but actively completing the survey was implied (and stated) as the consent to participate. Any participant who withdrew had data removed.

RESULTS

The response rate and participant characteristics for those who participated in each round of the survey are reported in figure 1 and table 4 below.

Round 1 of the survey obtained baseline information from our experts on which areas of rehabilitation and RTS required more research. The open-ended responses were grouped and analysed thematically (see tables 5–7).

Consensus statements were constructed, refined and agreed after facilitated debate at the face-to-face meeting days. Statements were sent in round 2 of the survey to a wider body of global experts and the LOA with statements are represented in tables 1, 2 and 7. Those statements reaching 70% agreement or above are highlighted. Typical discussion points are also shown to display common responses and disagreement from open-ended

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Table 1 Consensus statements and percentage agreement for round 2 survey—global expert panel and rehabilitation

Statements related to general rehabilitation		True	False	Undecided	Samples of typical responses—discussion points or areas of disagreement
Initial and progressive loading of injured hamstring muscles should include exercise with different: contraction types, muscle lengths, functional movements, body positions, but the type of exercise will depend on the sports-specific adaptation required, symptoms and risks of reinjury.		89.8%	8.5%	1.7%	Initial loading about neuromuscular stimulation and improving healing/ muscle tension at length not ideal/initial loading isometric to minimise stress or shearing on tendon/eccentric contractions should be the focus.
The order and speed of progression of exercises—(concentric/isometric/eccentric exercises), hip and knee-based exercises, inner and outer length exercises and open and closed kinetic chain exercises)—will depend on:	Adaptation required	96.2%	0.0%	3.8%	The level of agreement reflects the importance of the target adaptations required as a criterion for prescription.
	Symptoms	88.9%	7.4%	3.7%	Symptoms were the main criterion used by rehabilitation clinicians to make decisions.
	Type of injury	75.0%	15.4%	9.6%	Overall, the injury and tissue type were major considerations for clinicians in deciding on exercise.
	Risk of recurrence	60.4%	26.4%	13.2%	No comments made? Possibly reflecting the little literature available on this.
	Stage of tissue healing	90.7%	5.6%	3.7%	Tissue and stage of healing showed strong agreement—discussions suggested that it was harder to know at tissue level how healing was progressing, and symptoms were used as a surrogate to this.
The criteria for progression of exercise should include:	Symptoms pain	90.7%	1.9%	7.4%	Symptoms were the main criterion used by rehabilitation clinicians to make decisions.
	Strength	92.7%	3.6%	3.6%	While strength overall showed good agreement—there was less agreement on which components of strength were thought to be most important.
	Special tests	62.7%	13.7%	23.5%	Lack of agreement on specific tests—but a combination of factors was thought to be more important.
	Functional milestones	87.3%	5.5%	7.3%	Function was agreed to be important—but the panel could not agree on which functional milestones are most important.
	Flexibility	67.9%	17.0%	15.1%	Flexibility and range of movement (ROM) were thought by the panel to be less important as a criterion—and comments were that strength exercises at longer length were sometimes used to build flexibility concurrently with strength.
	The severity of the injury	73.1%	15.4%	11.5%	After the initial diagnosis and early treatment stage, the progressions were led more by the above criteria than the severity of the injury—although many issued cautions with tendon injuries and higher-grade tendon injuries due to risk of re rupture.
The dosage of exercise (frequency, intensity, duration) should be based on:	The response to previous loading	96.3%	1.9%	1.9%	Graded process of loading and assessing response—both during and after exercise—especially in terms of pain—it was felt this gave the optimum speed of rehab.
	Examination findings	88.2%	9.8%	2.0%	High agreement that examination was vital prior to progressions in dosage.
	Stage of Healing	86.5%	7.7%	5.8%	Appropriate healing level to tolerate applied loads.
	Periodisation factors	88.2%	3.9%	7.8%	Weekly and seasonal factors affect decisions on dosage and are key considerations in elite sport environments.
	Sporting level	82.7%	15.4%	1.9%	These three questions related to knowing the end goal in load capacity for match fitness, which will depend on type and level of sport.
	Current and previous capacity	88.7%	7.5%	3.8%	
	The target adaptations related to the patient's goals and or sport	92.3%	3.8%	3.8%	
	Strength	92.6%	3.7%	3.7%	Training principles of overload—ensuring strength loads are progressed to enable muscle to keep adapting—that is, avoid accommodation to the equivalent applied loads.
	Fitness	78.8%	13.5%	7.7%	Cardiovascular fitness may not affect dosage in gym-based work but will affect running work.
	Severity of the injury	84.6%	11.5%	3.8%	It may not be appropriate to load some injuries too heavily—as they may not have symptoms but still be at risk of retear—i.e. biceps femoris and central tendon involvement.
The whole rehabilitation process should be agreed within the MDT and have athlete engagement.		96.8%	1.6%	1.6%	MDT and athlete engagement were key—the discussions were around all the stakeholders' potentially conflicting goals and timeframes.
The patient's sport and previous level of participation will impact the progression of exercise selection and ultimate return to activity.		95.2%	3.2%	1.6%	The discussions were like the three questions above.
It is important to consider the possibility of sciatic nerve/neural symptoms when considering a patient's progression through rehabilitation. Neural mobility could be considered in treatment but the protection of the repaired or vulnerable tissue should be maintained.		90.5%	0.0%	9.5%	Strong agreement.
Adjuncts to rehabilitation, such as blood flow restriction (BFR), electrical stimulation and hydrotherapy should be considered in the early stages to enhance tissue healing and recovery (caution should be used with cuff pressures over repairing tissues when using BFR training).		68.9%	6.6%	24.6%	There was less uniform global practice when relating to use of adjuncts such as BFR—this reflects small evidence base only in HSI
Rehabilitation should be monitored with appropriate markers that are progressive with recovery.		98.4%	0.0%	1.6%	Monitoring was agreed but the most common form of monitoring was very varied—most panellists mentioned monitoring with global positioning system data allowing on field training/match play load data.
Final stage strengthening should aim to achieve adequate symptom free, outer range, eccentric and isometric strength in injured and uninjured limb.		95.2%	1.6%	3.2%	Panel had agreement on the types of strength to be achieved by final stage rehab—with outer length eccentric and isometric strength—in line with evidence on strength.

Continued

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Table 1 Continued

Statements related to general rehabilitation	True	False	Undecided	Samples of typical responses—discussion points or areas of disagreement
It is key during a hamstring rehabilitation to assess, treat and prescribe exercises addressing the whole kinetic chain.	90.5%	3.2%	6.3%	Panel agreed that biomechanical kinetic chain was important but there was less agreement on which were the most important components—many panellists suggested that it should be individualised and decided based on thorough subject and objective examination.

MDT, multidisciplinary team.

questions. The order of the statements is based around the decision-making stages of rehabilitation—early/middle/late/and RTR/RTS stages.

DISCUSSION

This modified Delphi aimed to reach expert consensus on the rehabilitation of HSI over three rounds, comprising two online surveys separated by a consensus group meeting which established consensus statements around: rehabilitation (11), RTR (8) and RTS (12). Further expert voting in the final round online survey further refined these statements, with key statements reaching the a priori agreed 70% agreement (rehabilitation (11), RTR (8) and RTS (9)). The discussion is ordered around the consensus statements relevant for the stages of rehabilitation—early/middle/late stages.

Initial and progressive loading: type and dosage of exercise

Exercise prescription should aim to prepare the injured hamstring for the sports-specific capacity required (LOA 89.5%). Multiple types of exercise were agreed to be important but there was no agreement on which exercises were best at each rehabilitation stage. When deciding on initial loading, pain, athlete confidence and classification of injury were important, but flexibility, gait and strength were ranked low. This is not aligned with evidence, suggesting that strength in outer lengths and flexibility are both associated with early rehabilitation progression,[61] but other reviews suggest range of movement (ROM) and flexibility are less important.[62 63] Motor control and recruitment were not prioritised by as many experts, possibly reflecting lower volumes of evidence and difficulties with measurement. Clinical reasoning to inform load prescription using assessment and specific criteria, rather than time associated prescription, was preferred. Outer length eccentric and isometric strength capacity was required by the end stage of rehabilitation, in alignment with review evidence on prevention of injury[17 18 64] and prevention of recurrence.[65 66] The response to previous loading and strength (92.3% LOA) should be prioritised to decide the dosage of exercise/load (LOA 96.2%).

Influence of tissue healing

The stage of healing was important in deciding dosage of loading (LOA 86%). Components of muscle tissue (fascia, muscle cells and tendon) heal and adapt to loading at different rates after injury[67] and this has implications for time frames of healing, loading and recovery.[68 69] Rehabilitation should be clinically reasoned and individualised, based on the type of injured tissue, and its speed of healing and adaptation.[70–74] Optimising progressive dosage of loading (volume, frequency, intensity and duration) should encompass sufficient overload to promote adaptations but not cause tissue reinjury,[75] which may vary for

Table 2 Consensus statements and percentage agreement for round 2 survey—global expert panel and return to running

Statements related to return to running	True	False	Undecided	Samples of typical responses—discussion points or areas of disagreement
On pitch/track/field (sport specific) running is a significant part of hamstring rehabilitation.	98.4%	1.6%	0.0%	Levels of agreement for these two questions reflects the importance of running as part of hamstring injury (HSI) rehabilitation.
Running dosages should be gradually increased to ensure return to full sprinting.	100.0%	0.0%	0.0%	Hamstring muscle function discussed and difference in function at speed was acknowledged.
Sprinting dosage loads should approach game level intensities and volumes to reduce risk of recurrence on return to sport.	95.2%	4.8%	0.0%	Sprinting in games presents injury risk and sprint work is a key component in final phase rehabilitation.
Further research should investigate the specific actions, bias, roles of individual muscles in function of running and sprinting to aid rehab exercise prescription.	84.7%	0.0%	15.3%	Differences in muscle roles were discussed and the panel expressed need for more research into how the differences in muscle function will then impact rehabilitation.
Further research should investigate types (styles) and dosages of running (quantity, speed) that promote adaptations but reduce risk of recurrence.	90.3%	1.6%	8.1%	Discussions suggested that running had not been prioritised sufficiently in literature and identified a research need.
Further research should investigate safe time frames to commence running post HSI or surgery.	90.3%	1.6%	8.1%	Risk of reinjury is high when re-exposing HSI athletes to running—and the panel wanted after time frames for return—and more research into timeframes.
Mild pain with running is permissible in rehabilitating certain HSI, but we need to consider the function of the individual, the anatomy, injury, classification and the 24-hour pain pattern (subjective and objective).	83.9%	9.7%	6.5%	The panel acknowledged many athletes have pain when restarting running—there was less agreement on how much pain was permissible/deleterious—the stated consideration factors reached agreement but other factors did not.
In HSI, pain-free running is a criterion for return to sprinting.	85.5%	8.1%	6.5%	The panel agreed that pain levels should be reduced prior to permitting sprinting—the panel acknowledged that the initial commencement of full sprinting—was a high-risk period for reinjury.

MDT, multidisciplinary team.

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Table 3 Consensus statements and percentage agreement for round 2 survey—global expert panel and return to sport

Statements related to return to sport	True	False	Undecided	Samples of typical responses—discussion points or areas of disagreement
In hamstring injury, range of motion is a consideration for return to sport (RTS). If previous data is available, then within 10% of previous scores should be used otherwise within 20% of the other limb.	45.0%	23.3%	31.7%	Flexibility was not considered a key factor by many clinicians—stretching did not always produce improvements in function or performance and less agreement over acceptable levels.
Kinetic chain strength/function is a consideration criterion for RTS.	78.3%	6.7%	15.0%	All agreed kinetic chain was important—but panel did not agree on key kinetic chain factors. A clinical reasoning approach was advocated to assess each athlete based on the required sporting demand and key injury risk activities.
Progression to peak isometric force in mid and outer range, isotonic strength (eccentric only/eccentric and concentric) are all considerations for RTS.	83.3%	1.7%	15.0%	Optimal types of exercise were controversial but consistent with literature—eccentric or isometric exercises at length were considered important and reached agreement.
Benchmarks for strength should reflect the end goal demands of the athlete but should be within 10% of previous data or population means.	66.1%	10.2%	23.7%	The low agreement for this question reflected differences in opinion on strength benchmarks.
Athlete subjective apprehension is a consideration for RTS criteria.	98.3%	0.0%	1.7%	The strong agreement reflects the importance the panel placed on the athletes leading the RTS/return to running process—and ensuring their opinion was prioritised.
Athlete self-assessment of their readiness to RTS is a key factor in the RTS decision-making process.	86.7%	5.0%	8.3%	
Askling H-test is a useful test in the return to sprinting decision process.	57.6%	18.6%	23.7%	The respondents were divided on use of pain provocation tests. Their usefulness was acknowledged but it was felt that no one specific test could assess readiness to return to sprinting—and the tests should form part of an ongoing assessment and clinical reasoning process.
Endurance capacity testing of the hamstrings should be a consideration for RTS.	78.3%	6.7%	15.0%	Endurance was felt to be important, but it was harder to get agreement on which endurance tests were most important—running endurance was felt to be important but the panel suggested that the level of endurance related to the specific sporting demands.
Pain-free sprinting is a criterion for return to play.	96.7%	1.7%	1.7%	The importance of sprinting in match play/competition was acknowledged, with high agreement. There was less agreement on the dosage of full sprinting. While some pain was permitted in running, sprinting in RTS—was expected to be pain free.
Completing full unrestricted training session should be a criterion for RTS.	93.3%	6.7%	0.0%	Training sessions reached agreement—particularly as this assessed the athlete with sports-specific demands and endurance requirements.
The use of previous GPS metrics can guide the required dosage of appropriate metrics, that is, volume, sprints, speed, high-speed running.	83.3%	3.3%	13.3%	Many in the panel were using GPS to measure running dosage—and their usefulness was thought to be key—with practice expertise moving faster than research evidence base—this was thought to be an area requiring greater research.
RTS should be a multidisciplinary process that involves all stakeholders ideally.	98.3%	0.0%	1.7%	The importance of a whole MDT and coaching athlete stakeholder involvement reached hight level of agreement—but many clinicians acknowledged significant pressure from stakeholder groups to modify their clinical decision-making.

GPS, global positioning system; MDT, multidisciplinary team.

each myotendinous structure (fascia/muscle/musculotendinous junction (MTJ)/tendon). This follows evidence of faster time frames for healing of myofascial (type a),[76] versus MTJ (type b), which heals via satellite cell induced myogenesis and tendon (type c) injuries,[77 78] which depend on collagen synthesis and replacement and remodelling.[79 80] The type of tissue may influence the amount of early protection required[80] and the risk of recurrence, with more protection required and greater risk in type c or tendon type injuries.[81] Hamstrings have complex intramuscular tendon architecture and injuries to these structures are often poorly recognised,[82] with poor rehabilitation outcomes[83] and may require further protection, although this remains controversial.[84] Repaired tendon tissue may not regain preinjury biomechanical properties, even at 12 months.[85] Longer protection may be required, particularly from elastic or strain loads like running, sprinting, jumping and other sports-specific movements requiring tissue elasticity[6] (LOA 92.3%). For HSI, our panel suggested early protection may be required from activities such as weight-bearing (high-grade injury), stairs and high force contractions, contraction at long lengths, eccentric contractions and stretch shortening cycle (SSC) contractions (jumping, plyometrics and running). They disagreed, however, on the time frames for protection, with most suggesting that timing or protection should relate to presence or level of symptoms. Symptoms, however, were thought to provide only a surrogate measure of healing, and in some types of injury, adequate fixed tissue healing time may be required (ie, tendon and CT injuries). Symptoms may resolve while the healing tissue is still vulnerable. This represents a conflict between symptom-based and time-based rehabilitation approaches and both may be required.

Commencement of loading and exercise prescription

After initial protection, the primary rehabilitation goal is to progressively load recovering tissue to promote its optimal adaptation back to full strength, elasticity, capability and function.[6]

The type of muscle contraction prescribed in exercise (eccentric,[35] isometric[86] and concentric[87]) produces different force

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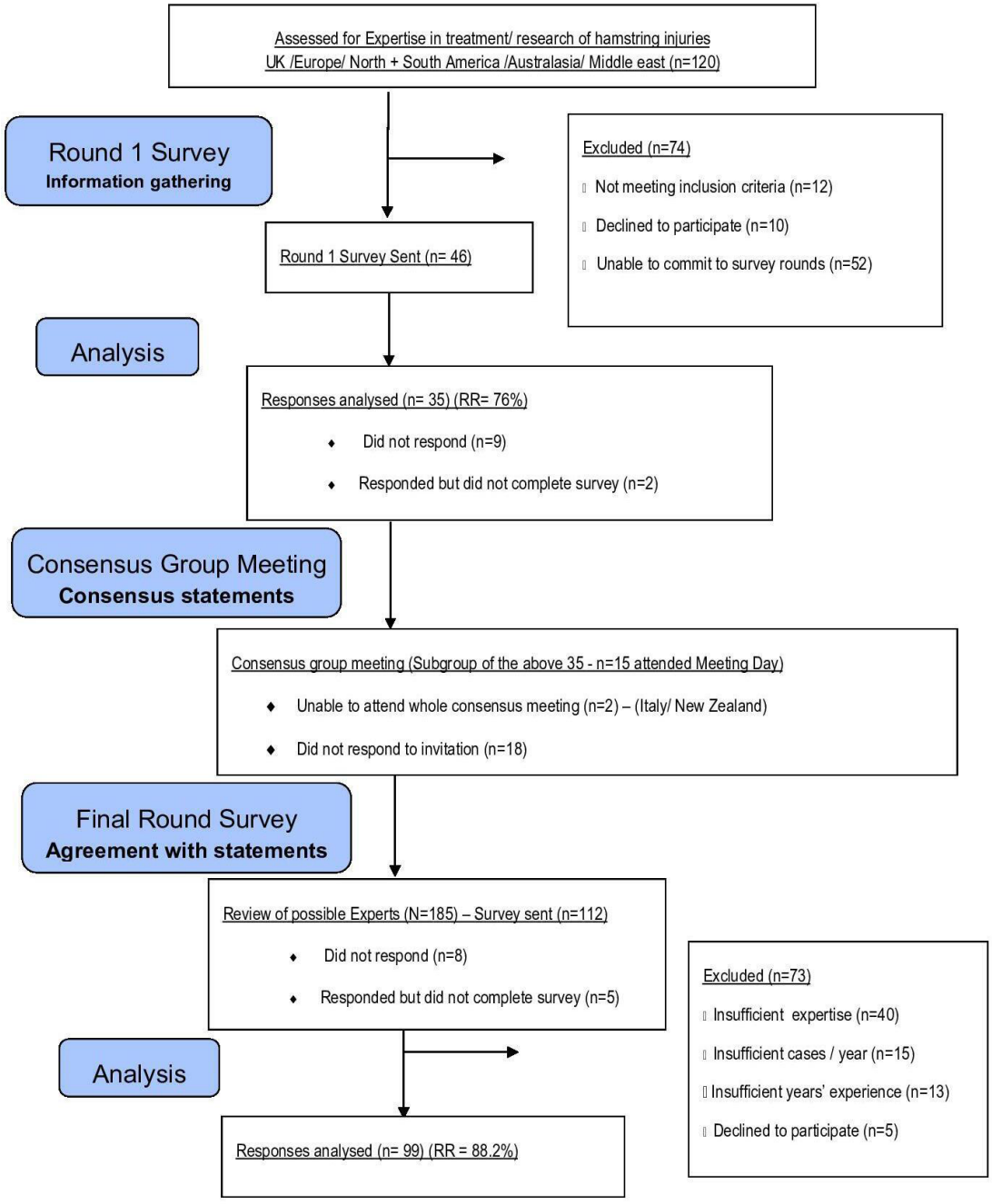


Figure 1 Flow diagram of expert participants and response rates (RR).

outputs and loads on muscle tissues, leading to different adaptation and requiring different periodisation and recovery times.[88 89] Early eccentric loading was typically avoided by our experts due to perceived reinjury risk and loading commences with isometric contraction at shortened lengths. This follows historical guidance.[90] Isometric contractions, however, (depending on the muscle length and effort) can produce greater tensile force loads within tendinous CT than do eccentric loads.[91] Heavy loads may, therefore, be applied too early, but this may inadvertently allow earlier adaption within CT and speed rehabilitation. However, some of our panel and some authors suggest that it may be advantageous to safely expose tissue to paced eccentric loads.[28 92] Outer length, eccentric and isometric strength work was certainly an ultimate goal (LOA 95%). Loading hamstring at longer lengths may increase fascicle length,[92 93] changing the length tension relationship in muscle and reducing injury risk.[94]

The hamstring muscle group comprises two joint muscles and muscle function differs depending on the mobile joint, but also whether the mobile segment is fixed (or in a closed kinetic chain) or free, in an open kinetic chain. Recruitment will differ with reversal of the mobile versus fixed attachments.[95 96] For hamstrings, hip versus knee dominant exercises load different parts of the muscles,[97–100] with different training effects. Our panel advocated applying both types, but without agreement on which should be first.

Exercise speed and elastic function in rehabilitation prescription was emphasised by only small numbers in our panels (outlier view), but evidence suggests that adaptations to training

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Table 4 Participant characteristics of the expert panels

Characteristic	Categories	Survey round 1 N=35	Meeting N=15	Survey final round N=99
Sex	(M:F)	33:2	14:1	81:18
Age (years)	27–36	11 (31.4 %)	6	32 (31.6%)
	37–46	13 (37.1%)	4	33 (33.7%)
	47–56	9 (25.7%)	4	20 (20.4%)
	57–70	2(5.7%)	1	14 (14.3%)
Role clinician	Clinician only	3 (5.7%)		26 (25%)
	Researcher/scientist only	2 (8.6%)		11 (11 %)
	Clinician+researcher	30 (85.7%)	15 (100%)	62 (63%)
	Neither clinician nor researcher	0		1 (1%)
Hamstring cases/year	None	0		5 (5%)
	0–5	1 (2.9%)		6 (6%)
	5–9	6 (17.1%)		25 (24%)
	10–14	7 (20%)		12 (12%)
	15–19	10 (28.6%)		13 (13%)
	20 or more	11 (31.4%)		38 (38%)
Healthcare profession	Sports medicine physician	4 (10%)	1 (7%)	21 (18 %)
	Orthopaedic surgeon	8 (21%)	5 (35%)	18 (17 %)
	Physical therapist	22 (55%)	10 (64%)	43 (40 %)
	Sports scientist	1 (3%)		25 (24 %)
	Athletic trainer/strength and conditioning coach	2 (5%)		7 (6 %)
	Other	2 (5%)		2 (2%)
Country of practice	North America	4 (11%)		10 (10%)
	Europe	26 (66%)	12 (80%) (UK, Neth, Ir)	65 (64%)
	Middle East/Africa	4 (11%)	1 (7%) SAf	12 (12%)
	Southeast Asia			1 (1%)
	South America			1 (1%)
	Australasia/pacific	5 (13%)	2 (13%) (Aust)	10 (10%)
Sports	Football	31 (29%)	4 (27%)	79 (80%)
	Athletics	19 (19%)	2 (13%)	59 (60%)
	Rugby codes	13 (12%)	4 (27%)	40 (40%)
	NFL (North American football)	5 (5%)		9 (9%)
	AFL (Australian Rules football)	3 (3%)		9 (9%)
	Basketball	9 (9%)		30 (30%)
	Volleyball	4 (4%)		1 (1%)
	Skiing and winter sports	9 (9%)		21 (21%)
	Hockey	3 (3%)	1 (7%)	22 (21%)
	Judo/martial arts/wrestling	2 (2%)		24 (24%)
	Cricket			15 (15%)
	Ice hockey			12 (12%)
	Acrobatics/gymnastics/dance			17 (17%)
	Gaelic football			7 (7%)
	Racquet sports			17 (17%)
	Handball			20 (20%)
	Other	9 (8%)	4 (27%)	6 (6%)
Years working with hamstring injury pathology	0–4	5 (14.3%)		17 (17%)
	5-9	8 (22.9%)		13 (13%)
	10-14	9 (25.7%)		22 (21%)
	15–20	4 (11.4%)		23 (23%)
	More than 20	9 (25.7%)		24 (24%)
Highest academic achievement	Bachelor/diploma			14 (14%)
	Masters			35 (35%)
	PhD			34 (35%)
	Clinical doctorate			15 (15%)
Had hamstring injury personally	Hamstring problem			38 (38%)
	Not applicable			61 (62%)

Aust, Australia ; IR, Ireland; Neth, Netherlands; SAf, South Africa.

are influenced by contraction speed and elastic function. Muscle CT is an elastic energy store and tendon strain and elastic/spring behaviour are vital to hamstring muscle function, but involve high tensile loads on the tendon and muscle CT.[101] This elastic/spring behaviour must be restored for activities such as running or jumping.[102] Elasticity also works across long fascial slings of CT, as well as within individual muscles.[103] Deciding when to allow elastic load and SSC activities has importance,[102] including running at low and high speeds.[104] Reinjury risk is high during introduction of these activities.[81 105] In SSC and elastic work, the speed of activity increases strain rates on CT, placing the CT under greatest load and risk, although high strain amounts may be tolerated by recovering tissue if applied slowly, and may stimulate connect tissue cells/fibroblasts, tenocytes to adapt fastest. This raises the importance of the speed of the exercise. In hamstrings, as running speed increases, elastic strain behaviour, the amount of negative work[106] and force[107] all increase. Typically, our experts reported not exposing injured tissue to running early, but in certain injury types, in controlled situations, this loading, may allow earlier tissue adaptation.

We did not reach consensus around neural activation and motor control, which were only highlighted by small numbers on our panel (outlier viewpoint), reflecting some evidence finding neuromuscular deficits and inhibition after HSI.[108–110] Many clinicians include exercise for muscle activation, to address this inhibition and control,[111] and different hamstring exercises activate muscles very differently,[112–114] with implications for neural components to strength. Reinjury risk can be higher with lower levels of muscle activation in warm up.[115] Neural movement may be important, with neuromeningeal mechanisms to some HSI proposed,[116] and assessment and treatment of neurodynamics can have significant effects on symptoms and flexibility.[117–119]

Flexibility

The commencement of flexibility work recommended after HSI is varied and we did not reach consensus. Lack of hamstring flexibility is a possible risk factor for HSI and reinjury[120] but can be present after injury.[121] Some authors advocate flexibility work after HSI[34 122] but other evidence suggests flexibility may not be a risk factor for reinjury.[63]

Monitoring and progression of exercise

Progression of exercise maintains ongoing adaptation to training.[123] There was strong agreement for monitoring through rehabilitation (LOA 98.4%). Exercise progressions should ideally be made based on criteria. Having specific adaptation goals (LOA 96.1%), considering tissue healing (90.4%), or the type of injury (75%), and using symptoms (88.5%), such as pain, were considered important criteria for progression. There was less agreement on recurrence risk (60.4%) affected decision-making. Risk of recurrence did not reach consensus. This may reflect the lack of research into what types or speeds of progression affect reinjury risk. Strength, rather than pain, was the most important criterion for progression, indicating that some clinicians prefer to tolerate some level of pain (pain threshold), although, a high proportion of the panel wanted tissue to be pain free prior to progression.[28 92]

We did not achieve consensus on the optimal order of exercise progression but did agree that this should be individualised based on the level and type of sport and required capacity (LOA 95%). Rehabilitation should be commenced and progressed with a sport-specific end target goal/capacity (LOA 96.2%) and that loading of the injured muscle(s) should follow the muscle actions, demands roles in the athlete's sport and level of play. Injury patterns in some sports relate to slow speed stretch type forces with contracting muscles.[124] Sports such as rugby or American football see different HSI mechanisms with high load slow stretch injury, typically involving the semimembranosus and

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Table 5 Round 1 survey: what are the key questions that you would like answered regarding the early phase of rehabilitation after hamstring injury (HSI)?

Domain area (theme)	Responses	Typical responses
Early interventions (STM/neural mobilisation /+adjuncts blood flow restriction/EMS)	9	Is there a role for adjunct treatment modalities? At what time point are they safe and to what level of intensity?
Progression criteria (including pain)	6	What outcomes should we be aiming to achieve for criteria-based progression along stages?
Optimum exercise/load types	6	What are the optimal exercises to use in this phase? How early can we safely prescribe eccentric/long length exercises?
Pain importance	5	What are the outcomes of pain monitored/threshold approach to rehabilitation?
Modalities for inflammation/healing (RICE, Meds)	5	Does prolonged use of ice, compression or medication positively or negatively affect hamstring healing rates?
Timescales (start and progress load)	4	How early can we safely prescribe eccentric/long length exercises?
Flexibility/range of movement	3	Is there a role for knee flexibility work?
Immobilisation and bracing (optimum, effects)	3	Does initial immobilisation positively or negatively affect hamstring healing rates?
Neural factors, inhibition and activation	3	What are the outcomes of return to run process, early versus delayed versus criteria based, versus early introduction of eccentrics—any effect on neuromuscular inhibition?
Optimum dosing (frequency, intensity, duration)	2	What exercise dosages are optimal for loading early phase after hamstring injury?
Safety of early loading	1	Does early mobilisation/rehab including stretching and activation of the hamstring speed or limit recovery?
Tissue strain load/exercise	1	What is the strain placed on muscle/tendon by different rehab exercises?
Weight-bearing	1	When does initial reduction in weight-bearing help or hinder healing?
Early strength	1	What are the outcomes of early introduction of eccentric exercises?
Total	50	

EMS, electromagnetic stimulation; RICE, rest, ice, compression, elevation; STM, soft tissue massage.

fascia, with extremes of hip flexion and knee extension.[124 125] Sports involving jumping, pivoting or kicking[126] differ again in hamstring and lower limb kinetic chain function.[127] Rehabilitation exercise should, therefore, be chosen, adapted and targeted specifically to the functional requirements of the injured muscle[98 111] in the sport and its injury risk movements.

It is historically suggested that knee-based exercise be introduced prior to hip-based exercise. Hip-based protocols such as the L Protocol require the hamstrings to function at longer muscle lengths and are effective in elite sprinters[23] and footballers[24] for HSI prevention. The advantage of hip over knee-based protocols, and when to commence them, is less clear in rehabilitation. Hamstring contractions in high-speed running (HSR), however, involve controlling concurrent knee and hip high-speed single leg angular motions[128] and it may be appropriate to consider biarticular single leg exercise.

Subjective and objective longitudinal monitoring throughout rehabilitation

Progression of rehabilitation should be reasoned and based on ongoing assessment including both subjective and objective

Table 6 What questions would you most like answered on exercise prescription in hamstring injury (HSI) rehabilitation?

Domain area (theme)	Responses	Typical responses
Progression of exercise	8	What is optimum order of progression of exercise? inner to outer? short length to long concentric to eccentric to isometric? open kinetic chain versus closed kinetic chain? knee to hip based?
Dosage	5	What is the optimum dosage of strength exercise?
Contraction types	5	What type of contraction should be emphasised during hamstring injury rehabilitation?
Running/sprinting	4	What is a safe but stimulating dosage of pitch-based running?
Exercise choice	4	what are the optimal exercises for hamstring injury prevention?
Importance of symptoms	3	How effective is early introduction of eccentrics and pain threshold training?
Safety versus effectiveness balance	3	What is a safe but stimulating dosage of strength exercise?
Tissue healing stage	2	What modes of exercise should be carried out at certain healing stages?
Timing	2	When should certain exercise types, isometric, concentric, eccentric, stretch shortening cycle be implemented throughout rehabilitation?
Insufficient evidence	2	Can we get more insights to the specific mechanisms of HSI at a contraction mode, neural and structural level to aid prevention and rehabilitation exercise choices?
Flexibility	1	What are the effects of flexibility exercises?
Strength	1	What types of strength are crucial?
Which muscles	1	How best do we target loading the biceps femoris long or short head and do we need to?
Functional exercise	1	More randomised controlled trials (analogous to those employing the Nordic) exploring the functional effectiveness of different exercises.
Neural factors	1	Which exercises promote optimal hamstring activation?
Total	43	

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Table 7 What are the questions you would like answered on return to running and sport after hamstring injury?

Domain area (theme)	Responses	Typical responses
Running mechanics	8	Does early return to running effect rehab outcomes?
Optimum monitoring	7	What key benchmarks should we be considering before each stage and research about?
Recovery	2	How long to leave it between bouts of high-speed running?
Sport specifics	3	What are the sport-specific match demands that we can replicate towards the end of rehabilitation?
Load tolerance	1	Does early return to running effect rehab outcomes?
Strength	3	What are key strength components and levels to enable safe return?
Dosage	2	What dosage of running should be permitted before sprinting is safe?
Timing	4	How early is it safe to sprint?
Total	30	

measures,[129] as well as evidenced-based criteria. Many of the criteria that clinicians use to progress load are investigated only in subsets of the HSI population[61] or not at all.[28]

Imaging

None of our expert panel recommended using imaging findings as criteria for progression, and this was not added as a consensus statement. MRI findings show poor significance at RTP[130 131] and our outcomes align with another consensus statement in football, where medical imaging was not recommended to inform RTS decisions.[49] While imaging is used for classification and grading of injury, which assists rehabilitation prescription in practice,[16 29] imaging could not be used to determine restoration of muscle and CT architecture and load capacity.

Clinical examination findings/assessment

Many studies use clinical examination components as the main decision-makers for progressions as they show greater predictive value than imaging modalities such as MRI.[132 133] Several studies have investigated the most important examination findings.[134–137]

Pain was the most important criterion for rehabilitation progression (LOA 90.4%). Traditionally, the absence of pain was the criterion for progression,[40] although some pain is acceptable[28 49] and rehabilitation with a permitted pain threshold has been found to be beneficial.[65 138 139] Slower pain-free progression is advocated in high-grade or tendinous HSIs.[16 140 141] Pain threshold rehabilitation may not accelerate time to RTS, but may accelerate restoration of isometric knee flexor strength and maintain biceps femoris long head fascicle length, compared with pain-free rehabilitation.[92]

ROM/muscle flexibility scored highly with our experts as progression criteria (LOA 67.9%) but did not quite reach consensus threshold. Some evidence suggests that flexibility and ROM tests, however, may correlate with time to return to sport.[61] Tests such as Maximal Hip Flexion Active Knee Extension (MHFAKE)[142] and straight leg raise[120] may be useful. Clinicians may also consider the use of modified Thomas Test[143] or a slump test for neurodynamic assessment.[118 119]

Muscle strength was scored highly by our panel as a key examination progression criterion (LOA 92.5%), following evidence of strength tests correlating closely with clinical progression and running effort.[61 132] We did not have consensus on the most important types of strength or optimum measurement methods but agreed that outer length and eccentric strength were key (LOA 95%). This follows evidence that outer length tests correlated more with progression than mid or inner range strength tests.[61 132] Quick convenient tests, such as manual muscle tests show low validity and reliability.[144 145] Instrumented tests such as handheld dynamometry (HHD) are more reliable, but still show questionable validity and reliability.[146] Tests such as prone knee bend testing at 15° with HHD[26] or knee flexion in supine with hip flexed, which test outer length hamstring function, can better mimic sporting or injury risk situations. Other measurement devices such as the Nordbord[147] have been used as a criterion for RTS and progression, citing evidence of Nordic hamstring exercise (NHE) to prevent HSI[148] but a recent meta-analysis reported inconclusive evidence of NHE preventing HSI.[149]

Other muscle strength tests, such as hand held dynamometry and isokinetic dynamometry,[150] and the derived hamstring to quadriceps[151] or concentric to eccentric[121 152 153] ratios may be beneficial,[28] although other evidence suggest less utility to predict risk of reinjury[154 155] or RTS.[156] Tests, however, cannot isolate/quantify individual hamstring or posterior chain muscle contribution[157] and other knee and hip muscles, such as gastrocnemius or adductor magnus, may compensate for hamstring muscle deficits. The different sport-specific body positions, functional roles and speeds of the individual hamstring muscles in sporting tasks (ie, sprinting) are difficult to assess with these tests and our experts reported combining these tests to measure multiple parameters of strength.[158] More valid/sports-specific tests to aid progression in strength prescription in rehabilitation are needed.

Some of our experts used surface electromyography (sEMG), measuring the contribution of each posterior chain (hamstring) muscle in exercises and detect neuromuscular inhibition[108]; however, other authors highlight poor validity and reliability of sEMG.[159] Further research is warranted, as some central nervous system changes are present after HSI[110] and may be implicated in recurrence.

Adjuncts

Adjuncts to strengthening which enhance muscle adaptation, but with lower tissue joint loads are frequently used in early rehabilitation. Examples include muscle stimulation and strength training with blood flow restriction (BFR), which allow earlier commencement of strength training, at lower levels of load. Their utility did not reach consensus in the final round (LOA 67.8%), although BFR was used by all the rehab clinicians in our consensus meeting panel, reflecting differences in global clinical practice. Few studies have examined their use after HSI. There is growing evidence for effectiveness in other conditions such as anterior cruciate ligament reconstruction,[160] and our panel reported adapting protocols for HSI.

The use of EMS and hydrotherapy was identified as being part of current practice,[161 162] particularly in the early phase of

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rehabilitation,[26] although the optimal use of these modalities remain unknown.

Contribution of the kinetic chain

During hamstring rehabilitation, it is important to assess the kinetic chain (LOA 90.2%), but there was less agreement on which structures to prioritise. Several clinicians commented on posterior chain muscle sling function, suggesting that treatment should be individualised, based on assessment and clinical reasoning, with correction of dysfunctions as a criterion for RTS (LOA 77.6%). The statement around sciatic nerve showed strong agreement (90.5%), reflecting its proximity and frequent involvement in high-grade HSI, where the nerve can be tractioned or tethered. Associated symptoms warrant investigation and possible surgical consideration.

Some of our experts suggested hip and pelvis biomechanics influence HSI risk. Sacroiliac joint mobility and force closure[163 164] and ilial asymmetry both affect the pelvis and ischial tuberosity position, altering length tension relationships in the hamstrings. Pelvic control and gluteal muscle activation associates with HSI in running.[165] Gluteal versus hamstring contribution in hip extension,[166] femoroacetabular impingement,[167 168] lack of hip flexion,[169] lumbar spine L5/S1 nerve root pathology[170] and trunk strength with altered EMG activity[171] have all been implicated in HSI risk. Other studies, however, do not implicate proximal kinetic chain muscles after HSI and the picture may be more complicated.[172] Our panel advocated for a kinetic chain approach that individualises assessment and clinical reasoning for each athlete.

Return to running

Running and sprinting were identified as a key components of rehabilitation after HSI (LOA98.4%) (table 6). This reflected literature suggesting HSR exposure[173 174] and poor prescription of running[64] are risk factors for HSI and reinjury. The hamstrings are integral to running and sprinting,[175 176] particularly in end swing and early stance phases[177] when large forces and rates/amounts of strain[178] are present within the hamstring CT.[101 104 179] In running, the three hamstring muscles show different activation, at different lengths[178] and velocities,[12 180] and with different force outputs.[98 111 175] In sprinting, semitendinosus undergoes the largest lengthening velocity, with semimembranosus, functioning with the greatest force production and biceps femoris undergoing the largest strain,[11 175] with some studies suggesting thatBiceps Femoris long head can reach 112% of its resting length[179 181] (possibly the reason why this muscle is more frequently injured in HSR mechanism[31 182 183]). The muscles may also function differently based on the levels of acceleration.[184] This may mean each muscle requires a different rehabilitation prescription for RTR.

Strong agreement between our experts highlighted that different hamstring muscles play different roles in running, which affects rehabilitation prescription (LOA 84.2%) and safe time frames to progress running (LOA 90%).

Criteria for RTR

Consensus was reached on a criteria-based approach rather than time frames for RTR but differed on their preferred criteria. Clinicians indicated their use of criteria related to pain, strength and flexibility, but assessed running specific muscle functions and capacities.[17]

Pain level was the main criterion chosen by the panel for RTR, either on examination (palpation)[65] or with a specific test or activity.[185] Some pain is expected, and they agreed mild pain may be acceptable (LOA83.1%) but did not agree on a tolerated pain threshold. They suggested a tolerated threshold level of pain was preferred, decided between the athlete and rehabilitation team.[92] Further research was recommended on the relationship between pain, recovery time and reinjury risk during or after running (table 6).

Strength was chosen as a criterion for RTR, but with disagreement on what type or quantity of strength was adequate or again how to test. Many panel members identified outer length eccentric or isometric strength criteria, in line with literature on hamstring functional demands in running and rehabilitation programmes.[23 24]

The panel identified flexibility and ROM factors as important prior to RTR, with tests such as MHFAKE,[61] although the literature suggests flexibility is not a risk factor for reinjury.[63] Large differences were present in their choice of special tests for RTR, with examination type tests or jump/hop testing was also used,[186] in line with evidence on reactive strength index[187] as a risk factor for injury but these tests also lacked agreement, reflecting conflicting evidence on evaluating HSI risk using power and plyometric testing.[63]

Criteria for sprinting

No consensus was reached on criteria for safe return to sprinting, reflecting the lack of evidence quantifying sprint loads and risk of reinjury. There was 100% agreement that loads should be increased to full sprinting prior to RTS. This reflects their awareness of the hamstrings functional role in full sprinting and the increased tissue strain rates with elevated running speeds.[188] Progressing running too rapidly in rehabilitation may risk retear but altered running kinematics[63] and even insufficient running conditioning[189 190] may also increase risk of reinjury. More research into optimum dosages of running to prevent reinjury risk is needed (LOA 90%).

There was some difference in criteria that our panel used to permit return to sprinting, with higher speeds emphasised in strength testing. Few of our panel mentioned power or rate of force development testing, and clinicians disagreed on the required threshold of strength, often using only the percentage of strength of the uninjured limb—the limb symmetry index (%LSI) to quantify, but with strong acknowledgement that the unaffected limb was rarely normal. Special tests as criteria for sprinting (such as the Askling H-Test[185]) did not reach high levels of agreement (56.1%), but there was strong agreement on completion of submaximal running phases as a criterion for returning to sprinting, although the panel disagreed on threshold volumes, intensities or speeds. This reflects the lack of evidence around the dosages of running required to reduce injury risk, and our panel showed high LOA on the need for future running research into muscle roles (84.2%)/types of running (90%) and safe time frames (90%). Many of our panel prioritised global positioning system (GPS) data to benchmark, grade and target running loads, and evaluated on symptom response (pain tightness) to graded running loads. They agreed that pain-free running was a criterion for sprinting (LOA 85.5%). In the situation of sprinting, where injury risk is higher, pain-free versus pain threshold criteria were preferred.

Return to sport

We acknowledged that the RTS phase was a reinjury risk period and safe management was vital (table 7). Many athletes demonstrate deficits in function, despite being cleared to RTS.[122 147] The

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highest risk period for reinjury after RTS is the first month,[191] with risks raised for the first year[136] and competition running levels can remain suppressed even after RTS.[43]

Criteria for RTS

Several Delphi consensus studies outline RTS criteria,[48 49] emphasising pain (clinical examination/testing), functional performance, strength, flexibility and athlete confidence. While these components are acknowledged, we also identified criteria around running and return to full training and sports-specific criteria, correlating with performance. It should be noted that a decision to RTS is a shared decision and the clinician's role may be to provide information regarding risk rather than strict criteria to RTS.[192] However, completion of full unrestricted training sessions was crucial (LOA 93.3%), as well as pain-free sprinting (96.7%), with volume, speed and intensity at (and preferably beyond) competition levels. This reflects evidence showing ongoing deficits in force production and power in running—even at RTS,[193] although appropriate prescription and progression of loads can reduce reinjury risk.[189] It should also be recognised that in some sports, players can RTS but adjust their exposure to HSR loads.[43] Monitoring external running workload using GPS allows more quantifiable, on-field sports-specific (position-specific) loads, speeds as part of expert rehabilitation. The clinicians also recommended using historical training and match play GPS baseline data as a benchmark (LOA 83.3%). Running load metrics include: speed, accelerations, distance, direction changes and number of sprints efforts.[49 194]

We agreed that endurance was a consideration (LOA 78.3%) but there was less agreement on what type of endurance. It should be sports specific, relating to the sport's volume of high-speed running. This follows evidence suggesting increased risk of injury with lack of fitness[195] and fatigue.[196]

Factors such as ROM and flexibility, traditionally rated as important, failed to reach threshold agreement (45%). This may reflect evidence on flexibility and static stretching causing some detriment to elastic function and performance[197] and review evidence suggesting flexibility and ROM were less important as reinjury risk factors.[63] Few in the panel suggested imaging was useful for RTS decision-making, in line with current evidence.[63]

Strength

Strength as a criterion for RTS reached consensus but the group disagreed on which strength components were key. Mid and outer length isometric and eccentric strength was agreed on (LOA 83.3%) in line with evidence on types of strength deficits posing injury risk.[65 66] The quantity of strength required is not clear, particularly in relation to the uninjured side (including the frequent benchmark of <10% deficit) (LOA 66.1%). This reflects a movement away from %LSI as a strength measure due to loss of unaffected leg strength post injury. Preseason benchmark screening on variables such as strength/fitness, flexibility did not have a high LOA (64.9%) on which screening data to prioritise and what % difference was permissible. General population data were thought to be too non-specific. Sports differed in priority benchmark screening data and the %LSI considered acceptable. The panel suggested less correlation between strength components and the ability to run and more research may be required to understand if running criteria should be prioritised over strength criteria for RTS (90.3%).

Performance tests and sports-specific/position-specific testing

On-field tests of performance have also been used alongside running tests for return to play. These include hop and jump tests.[198] However, they may not replicate the type of match play hamstring loads. Special criterion tests exist, such as the Prone Hip Extension[199] and Askling H-Test[185] aim to reproduce hamstring loads during sprinting, but they are not performed upright, and do not approach the speed or amount of hamstring strain in sprinting, and did not reach agreement for use by our panel (LOA 57.6%).

Athlete confidence

Athlete confidence and apprehension ranked highly in criteria for RTS (LOA 98.6%). Player self-assessment, psychological readiness and confidence were seen as vital for RTS (86.7%), with negative emotions such as anxiety and fear avoidance detrimental to performance and pain.[200 201] Athlete confidence is the most significant predictor of return to full performance in some conditions such as ACL reconstruction.[202] However, in HSI, some athletes may present with few symptoms until sprinting, or SSC activity and athletes may feel ready to RTS but are still at risk of reinjury.

Our panel reported decision-making pressure from other non-medical factors[203–207] and players can RTS in spite of poor test results.[208] They strongly agreed that decision-making should include members of the medical/rehabilitation team, the coaches, other stakeholders and especially athletes themselves (LOA 98.3%)[192 209].

Limitations

There are many potential weaknesses of the Delphi and consensus research methodology. Bias is possible with inadequate stakeholder/expert inclusion/exclusion or with inadequate design of surveys or meetings.[210] In spite of invitation, many international round 1 expert panel respondents were unable to attend our face-to-face meeting days, The London 2020 international Delphi and hamstring consensus meeting group comprised 15 out of 35 respondents/experts (43%) to the initial survey. This could result in inclusion bias; however, the panel attending were heterogenous, with a mix of profession, sport, age and domain expertise in treatment of HSI. They comprised clinicians from Australia, Netherlands, Ireland, the Middle East, but the majority of the meeting panel were UK based. We sought and invited experts from Asia, Africa and South America; however, there were less identifiable experts (clinical or published), and they could not attend due to pandemic travel restrictions. This may mean their HSI management practices are not represented, possibly introducing a further bias. Our meeting panel all worked in elite sport in international jobs with work schedules with international patient/athlete cohorts. Many did not train professionally in the UK and their work experience and current work schedules comprised the USA, Africa, Middle East, Australia and Asia. They reported that many of their athletes trained internationally, reflecting the current international nature of elite and Olympic sport. To further reinforce the integrity of the consensus, and provide more international perspective, authors were included with significant Middle East hamstring work experience.

Our group had multiple domains of expertise. These included surgery, postsurgical and conservative rehabilitation, classification, diagnosis, running and RTS. It was harder to evaluate expertise in rehabilitation and RTS, and the criteria chosen for

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expertise were harder to establish for rehabilitation. Academic criteria were thought to be important, but very few rehabilitation specialists had published. Clinical criteria were therefore deemed important. For clinical experience, the number of patients seen annually with his by the expert was chosen (ie, quantity of experience), but it was difficult to determine the range of injury types or severity and gauge the quality of rehabilitation experience. Choosing criteria for expertise is difficult for any Delphi study and represents one weakness of this methodology.[211] While we trusted the survey respondents to complete only those fields that encompassed their expertise (the reason for lack of full response rate for every section), it may be possible that some respondents completed sections that were outside their domain and level of expertise or scope of practice. Open-ended questions in the first round meant that only the information that clinicians submitted was used and adapted for the basis of subsequent rounds.

The perspectives of some groups may be under-represented in this work, with coaches and athletes comprising a smaller proportion of our panel, and, their view is vital,[212] although 38% of the panel in the final survey had undergone HSI, possibly contributing to the 'patient/athlete' voice.

While we attempted to be inclusive, the representation of women is low in our panels, (2/39, 1/15 and 18/99). We found the response rates lower for the women experts we surveyed and invited to our meeting. It was found that female rates of publication are lower in HSI, with less publicly available information on expertise. This also holds for experts from low-to-middle income countries, and other deserving groups with lower publication rates, or fewer English language publications, and less publicly available information on expertise. This has been a weakness in other consensus research and the voices of these groups are also vital.

Recommendations for future research

The consensus panel members suggested the following area of HSI rehabilitation areas of future research: tolerability of tissue for early loading and the greatest injury risk loads or dosages, which order of progression of exercise was optimal, neuromuscular control of running, muscle tendon interaction/sling function and elasticity and optimum methods to measure and train these, and finally, the optimal and minimal effective doses of running exposure to reduce reinjury risk.

CONCLUSION AND RECOMMENDATIONS

Our Delphi study and expert panel suggest that rehabilitation prescription after HSI should be individualised, based on the athlete's sports-specific hamstring demands, the nature of the injury and required capacities. Decision-making should consider differences in hamstring musculotendinous tissue, individual muscle anatomy and functional roles. This should direct rehabilitation prescription for different muscles and myotendinous tissues after HSI. In early-stage rehabilitation, most experts advocate protection of injured tissue from elastic load or stretch shortening (high strain amount and rate loads), but the types of load/contraction and the order of their application varied greatly between our experts.

Experts recommend addressing dysfunctions in the whole lower limb and kinetic chain related to hamstring function. While not reaching consensus, many experts are increasingly using adjuncts such as BFR training to achieve early strength gains with lower tissue loads.

They recommend criteria of symptoms, strength and response to previous loading as criteria for progressing and dosing exercise and deciding on safety to RTR and RTS. Other criteria such as flexibility and special RTS tests are used less widely. On criteria related to pain, experts suggest some activities should be pain free through rehabilitation (sprinting), but with other exercise activities a pain threshold approach can be permitted. In later loading, experts aim to achieve full outer length strength and eccentric strength as a key criterion for RTR and RTS.

In later-stage rehab, experts advocate prescription of running and sprinting as a key component of HSI rehabilitation and as a key progression criterion for RTS. Experts focus on the demands and capacity required for match play when deciding the rehabilitation end goal and RTS—they continuously monitor and test athletes through rehabilitation and are using modalities such as GPS to give more sports-specific on-field information on loading and running dosages and RTS readiness and would like more research into optimising these testing modalities.

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