

Clinical implications from daily physiotherapy examination of 131 acute hamstring injuries and their association with running speed and rehabilitation progression

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ABSTRACT

Aim To investigate the association of daily clinical measures and the progression of rehabilitation and perceived running effort.

Methods A cohort of 131 athletes with an MRI-confirmed acute hamstring injury underwent a standardised criteria-based rehabilitation protocol. Descriptive and inferential statistics were used to investigate the association between daily clinical subjective and objective measures and both the progression of rehabilitation and perceived running effort. These measures included different strength, palpation, flexibility and functional tests. Inter-rater and intrarater reliability and minimal detectable change were established for the clinical measures of strength and flexibility by examining measures taken on consecutive days for the uninjured leg.

Results The progression of the daily measures was seen to be non-linear and varied according to the measure. Intra-rater reliability for the strength and flexibility measures were excellent (95% CI ≥ 0.85 for all measures). Strength (in the outer range position) and flexibility (in maximum hip flexion with active knee extension (MHFAKE) in supine) were best associated with rehabilitation progression and perceived running effort. Additionally, length of pain on palpation was usefully associated with rehabilitation progression. At lower perceived running effort there was a large variation in actual running speed.

Conclusion Daily physical measures of palpation pain, outer range strength, MHFAKE and reported pain during daily activity are useful to inform the progression of rehabilitation.

Trial registration number NCT01812564 and NCT02104258.

INTRODUCTION

It has been suggested that a key feature of sports injury rehabilitation is the identification of functional milestones to be achieved, and documenting progress using ‘*continuous evaluation, which is necessary to guarantee a confident and timely return to training and competition*’.¹ For the hamstring-injured athlete, the evaluation could include: range of motion (ROM), strength, subjective reports of pain or discomfort on performance of ‘functional’ testing, and/or quality of movement assessment. Currently validity of these assessment features is unknown. If a clinician performs two clinical assessment measures in an effort to document a patient’s

progress, and the results are conflicting, it is not known if the results of one test or another should be more strongly weighted in deciding to progress the athlete or not. To date, we have no information if any of our commonly performed daily assessment measures bear any useful relation to the progress of rehabilitation. Previous research suggested that while there were no objective measures which could be performed at baseline (initial) examination which usefully predicted return to sport duration, an increased accuracy was seen by looking at a combination of parameters at initial examination and 1 week later.² As there were only two time points available (ie, initial examination and 7 days later), this research was forced to use linear modelling to predict time to return to sports (RTS). Research in other areas of human tissue healing shows a non-linear rate of healing^{3,4} and animal models of muscle injury also appear to heal in a non-linear manner.⁵ While it is likely that muscle injury in athletes follows a similar non-linear rate of healing, there are currently no data available to describe the parameters for this.

Commonly, high-speed running is viewed as an important rehabilitation outcome after hamstring injury, and graded exposure to increasing intensity of running is used both therapeutically, and to assess readiness to return to sport.⁶ If the athlete is progressed too hastily, there is the risk of exacerbation of the injury and presumed lengthening of rehabilitation duration. Yet, too cautious resumption will also unnecessarily lengthen the rehabilitation duration. Ideally, there would be some clinical assessments available which could confidently be associated with running speed and therefore allow accelerated yet safe resumption of exposure to high-speed running during rehabilitation. To our knowledge, no research has investigated the association of clinical assessment features and either the progress of rehabilitation or running speed.

Therefore, the aims of this study were to investigate the association (and variance) of a series of clinical measures with both the progress of rehabilitation to return to participation, and running effort to better inform clinical practice.

METHODS

Study design

This study was a pooled cohort of two single-site prospective randomised controlled trials (RCT): the first RCT (the Growth Factor study) investigating



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Table 1 Eligibility criteria for the two RCT studies

GF study	HAR study
<i>Inclusion criteria</i> ▶ Male gender ▶ Age 18–50 years ▶ Acute onset of posterior thigh pain ▶ Presenting an MRI within 5 days from injury ▶ MRI confirmed grade I or II hamstring lesion ▶ Able to perform five sessions of physiotherapy a week at our clinic ▶ Available for follow-up <i>Exclusion criteria</i> ▶ Contraindication to MRI ▶ Reinjury ≤ 2 months after RTS² or chronic hamstring injury > 2 months ▶ Other concurrent injury inhibiting rehabilitation ▶ Unwilling to comply with follow-up ▶ Needle phobia ▶ Overlying skin infection ▶ Diabetes, immune-compromised state ▶ Medication with increasing bleeding risk ▶ Medical contraindication to injection	<i>Inclusion criteria</i> ▶ Male athletes ▶ Age 18–50 years ▶ Acute-onset posterior thigh pain when training or competing, identified as: – patient-reported incident event – patient-reported pain in posterior thigh ▶ Clinical diagnosis of an acute hamstring muscle strain injury, defined as: – localised pain during palpation of hamstring muscle – increasing pain during isometric contraction – localised pain when performing a passive straight leg test ▶ MRI confirmed isolated hamstring lesion ▶ MRI performed ≤ 5 days from injury ▶ Available for ≥ 3 physiotherapy sessions per week at Aspetar ▶ Available for follow-up <i>Exclusion criteria</i> ▶ Reinjury ≤ 2 months after RTS ▶ Chronic hamstring complaints > 2 months ▶ Grade III hamstring tear ▶ Contraindications to MRI ▶ Already included with prior injury

GF, Growth Factor; HAR, Aspetar HAMstring Rehabilitation; RCT, randomised controlled trial; RTS, return to sports.

the effect of platelet-rich plasma (ClinicalTrials.gov Identifier: NCT01812564) and the second RCT (the Aspetar HAMstring Rehabilitation study) comparing two different rehabilitation protocols (ClinicalTrials.gov Identifier: NCT02104258) for time to RTS after acute hamstring injuries, respectively. Written informed consent was obtained from all participants.

The first RCT has been completed, with 90 participants included between 2009 and 2013. The second RCT initiated in 2014 and is still ongoing. At the time of analysis (August 2016), 48 out of 90 participants have been randomised and completed their treatment.

Eligibility criteria

Additionally for this study, daily clinical measurement data had to be available (table 1).

Daily measurements

The assessment techniques have been documented previously^{2 7} and extended basic description of the daily measurements and rehabilitation protocol was released for information purposes, and is freely available online (https://www.youtube.com/watch?v=Fzex_zG1JtA http://www.aspetar.com/AspetarFILEUPLOAD/UploadCenter/636209313253275549_Aspetar_Hamstring_Protocol.pdf).

A summary and full description of these daily measures can be found in table 2.

Examiners

Five sports physiotherapists (four male, one female) (with a range of 7–30 years' clinical experience) performed the daily measurements. The initial measurements were taken by a blinded sports physiotherapist from a pool of 8 who subsequently did not take part in the treatment for that athlete.

The complete rehabilitation protocol followed is outlined elsewhere.⁷

Outcome measure 1: return to participation

The recent 2016 Consensus statement on RTS⁸ suggested that the return to sport continuum comprised achievement of first, return to participation (modified training), followed by return

to sport (participating fully in training or a match) and, finally, return to performance (returning to sport at the same level as achieved prior to the injury).

In our setting, at the completion of the three-stage physiotherapy rehabilitation programme, the athlete is required to perform repeated 30m sprints at self-rated 100% intensity as well as repeated 40m sharp direction-change movements at 100% self-rated intensity. If the athlete reports no adverse effects we permit return to on-field, sports-specific practice. Three stages of sports-specific training of increasing difficulty are then performed before being declared fit to return to sport. During these final three sports-specific stages, no daily physical measures are typically taken, only subjective wellness and pain reports—the athlete is required to report no ill effects from the previous day's training to be allowed to progress. For the cases documented here, these final three stages have taken usually three further days. After finalisation of the three sports-specific stages, extensive RTS examinations including clinical examinations and specific tests are performed to inform the RTS decision process.⁹

In this study, we defined our outcome measure 'return to participation' as 100% completion of the rehabilitation component (ie, the three physiotherapy rehabilitation stages), and commencing the sports-specific component. Note that athletes were therefore not cleared or permitted to RTS and match play for another 3 days minimum after this time.

Outcome measure 2: running progression

The association between perceived running effort (0%–100%) and each of the daily clinical measures was investigated.

Running effort was estimated by presenting the athlete with a visual analogue scale marked from 0% to 100%, explaining that a 100% run would equal a maximum effort sprint, while 0% would be the slowest possible speed that the athlete could run at. The running is performed on an indoor oval track with approximately 30m straights, approximately 100m around. The athletes start the straight portion of the 'run' from a walking start, and decelerate on the corners. Each time the athletes complete a set of the running (four laps, eight 'runs'), they are asked to rate how fast they thought they ran at their maximum effort during that set. The time of the run across the central

Table 2 Daily clinical examinations conducted. In each of the strength tests, athletes were instructed to stop pushing immediately if they felt any pain in the injured leg, and the maximum strength was recorded at this point. These measures were analysed both as the raw value (kg) and as a percentage of an individual athlete's daily maximum strength on the uninjured leg for that measure. For SLR and maximum hip flexion with active knee extension (MHFAKE), measures were taken once only per day and analysed both as an absolute value (in degrees) as well as the percentage of the uninjured side

Assessment name	Assessment description
Pain	Daily pain was measured with a numeric rating scale, where the athlete responds to the question: 'On a scale from 0 (no pain at all) to 10 (the worst possible pain you could imagine), on average over the last day, how much pain have you had?' ²²
Palpation	Palpation pain length was measured with the athlete prone and relaxed. The examiner began palpation from an area presumed to be pain free, carefully and firmly palpating both legs moving from distal to proximal, for both the medial and lateral hamstrings. The athlete reported if the injured leg felt painfully different to the uninjured leg, and the proximal and distal points of this painful area were marked and recorded in cm as the total length. Palpation length was analysed both as an absolute value (in cm) as well as the daily percentage of an individual athlete's maximum length. Maximum length was the maximum length of palpation seen at any time during rehabilitation—in every case this occurred in the first few days of rehabilitation.
Trunk flexion	In standing with straight legs, the athlete was asked to flex forward reaching down their thighs towards the floor. The distance they reach before stopping (thigh, knee, mid-shin, feet, floor) was recorded as well as whether there is pain or a non-painful stretching sensation which limits further movement.
Flexibility—SLR	A passive straight leg raise (SLR; hip flexion) test was performed with the athlete in supine, with the contralateral leg fixed by the clinician. A handheld inclinometer was placed on the mid-shin of the anterior tibial border and the clinician passively raised the athlete's leg, while ensuring full passive knee extension. The angle was recorded at the endpoint of maximum hip flexion with the knee extended as tolerated by the athlete, or if the athlete reported pain. If the clinician perceived firm resistance to further passive hip flexion or there was palpable onset of pelvic rotation, this was considered the end of the test.
Flexibility—MHFAKE	An adapted active knee extension test, named the Maximal Hip Flexion Active Knee Extension (MHFAKE) Test, ² was performed, where the athlete was asked to keep the hip in maximal flexion by clutching the thigh to the chest, with the hands holding opposite elbows, and then instructed to actively extend the knee until reaching the point of maximal tolerable stretch of the hamstring muscle or the point where pain was reported. The contralateral leg was fixed by the clinician. The angle of inclination of the mid-shin was measured at the endpoint of maximal stretch with the handheld inclinometer.
Flexibility—hamstring length—passive knee extension test (PKET)	With the athlete supine and hip flexed to approximately 90°, the examiner passively extended the knee. The angle of inclination of the mid-shin compared with horizontal plane was recorded.
Strength—inner range	With the athlete prone and the knee flexed to 90°, the examiner placed a handheld dynamometer (HDD) against the posterior heel and instructed the athlete to press against this, gradually building up force to a maximum (isometric 'make' test). The highest score of the three trials was recorded.
Strength—mid-range	With the athlete prone, and the leg raised passively with the toes off the bed a distance equal to the height of the length of the foot. An HDD was placed against the athlete's heel with a force perpendicular to the shank. The athlete pushed up against this dynamometer for 3 s, and when the examiner felt this had peaked, the examiner pulled down against the athlete's heel to establish a 'break' force. The highest score of the three trials was recorded.
Strength—outer range	The athlete was placed supine with a belt stabilising the pelvis, and the thigh flexed to vertical with the tibia horizontal (ie, 90° of both hip and knee flexion). The athlete was similarly asked to isometrically push down against this dynamometer for 3 s (towards knee flexion). When the examiner felt this had peaked, while holding the dynamometer against the heel, a perpendicular force was applied to the shank against the athlete's heel to establish a 'break' force. The highest score of the three trials was recorded.
Double leg squat	The athlete was standing adjacent to the treatment table, facing away, with the edge level with the knee joint line and attempted to squat and rise such that the buttocks touch the bed. Presence/absence of pain was recorded.
Single leg squat	The athlete was standing adjacent to the treatment table, facing away, with the edge level with the mid-thigh and attempted to squat and rise such that the buttocks touch the bed. Presence/absence of pain was recorded.
Walking	Athlete reported presence/absence of pain while walking.
Jogging	Athlete reported presence/absence of pain while slowly jogging.
Supine bridge achieved	Score 1 if the athlete is able to painlessly reach the starting position for a supine bridge (hip and knee flexed with feet on bed such that the heels are level with the position the popliteal knee joint line would be with the legs straight). Score 2 if in attempting to raise the buttocks from the bed the athlete can only lift partially, painlessly. Score 3 if the athlete is able to fully raise the buttocks from the bed three times. Score 4 if the athlete can perform three repetitions painlessly using only the injured leg. Score 5 if the athlete can painlessly perform three repetitions with the extended leg supported on a bench or the examiner's shoulder, with the examiner sitting on the bed.
Supine single leg bridge repetitions	Number of single (bent) leg supine bridge repetitions the athlete can painlessly perform at an approximate rate of 1 every 2 s to a maximum of 20.

27 m (marked with cones) of the 30 m straights is recorded by the examiner using a handheld stopwatch.

During each session, if the athlete is able to complete a set of 'runs' confidently and without any discomfort, it is suggested to increase the running effort by 5%–10% for each lap. If any discomfort is experienced, if the athlete does not feel confident or displays lack of adequate mechanics or control (visual evidence of 'limping' or 'favouring' a leg), the athlete is instructed to return to the previous set's perceived running speed. Once athletes rate that they are running at or beyond 70% of their maximum, additional direction change running (over a 40 m course, including 90° and 180° turns in both directions) is commenced. Athletes

are initially instructed to run 10% slower than they achieved on the straight line running.

In a typical session, the amount of running (three sets of four laps or eight 'runs') is approximately 700 m, and the three direction change runs a further 120 m. This is similar to the distance an elite football athlete would be expected to sprint in a professional match.¹⁰

Statistical analyses

We examined the correlation between these subjective and objective clinical findings with the individual's percentage of rehabilitation duration and running effort in several steps.

To normalise the duration of the rehabilitation across participants, the data for the entire cohort were pooled, and described as percentages of their individual return to participation duration. For example, two athletes, both at 7 days into their rehabilitation (ie, 7 days since their injury), one with an ultimate return to play (RTP) of 14 days, and another with 21 days, would be considered to be 50% and 33% completed, respectively, on this seventh day. This approach allows description of the individual clinical measures at comparable periods in rehabilitation, for example, 'strength' by some measure may be 60% restored when athletes are, say 25% through their rehabilitation.

Subsequently, to better understand the relation between these assessment findings and treatment progression, four steps were conducted.

First, simple scatter plots comparing each assessment outcome and treatment progressions were created, along with lines of best fit and their associated variance (adjusted R^2).

To describe the general relation between the individual daily measures and progress of treatment, lines of best fit were calculated using a fractional polynomial approach with a closed test algorithm.¹¹ This almost always resulted in the choice of an FP2 model.¹¹ Considering these data in concert with tissue healing studies which we suggest provide the most biologically plausible understanding of the associated mechanism, we concluded that linear associations were not appropriate approximations. With no other consensus, we arbitrarily fitted second-order polynomials to all the smoothed data as these were the most frequently seen solutions. It should be noted, however, that there was a wide variation for each of the individual associations in terms of both shape and fit.

After this, the data were smoothed by splitting into deciles (1%–10%, 11%–20%, and so on) and then calculating descriptive statistics (mean, SD, median, IQR) for each decile, for each assessment. In each case, as there were parts of the data which were not normally distributed, the median and IQR were chosen to best depict the typical progress of rehabilitation.

All these analyses were then considered together within a clinical reasoning framework. Specifically, clinical decisions were made in three separate domains:

- ▶ First, the slope of the lines of best fit was examined—a steeper slope provides more clinically useful information as it will be changing by a larger amount day-to-day than a flatter slope.
- ▶ Then the 95% CIs of the lines of best fit are considered—narrower CIs provide more trustworthy associations, however, if the 95% CI includes a flat line, this variable needs to be discarded since it plausibly is unrelated to progress.
- ▶ Lastly, the minimum detectable change (MDC) values are considered in the context of the magnitude of the change in each of the measures where they are available. If the MDCs greatly exceed the amount of change of a variable across the duration of treatment, then this measure cannot be considered clinically useful as the 'noise' exceeds the 'signal'.

Finally, where there was significant statistical covariance, and it was determined that different measures were estimating similar biological aspects (eg, strength being measured in mid and outer ranges) a single measure was chosen as best documenting progress with the previous features in mind.

This approach was repeated with running effort (1%–100%) replacing treatment progression. Variables considered not clinically useful were eliminated and the remaining candidate variables are presented in the Results section, while all assessments are provided as online supplementary material 1.

Inter-rater and intrarater reliability data for the measures of strength and flexibility were calculated by considering all pairs of measurements taken on the uninjured leg which occurred on consecutive days. For these data, the intraclass correlation coefficient (ICC; 95% CI) and MDC were calculated along with reference descriptive values: mean, SD, SEM, and range (table 3). For the strength measures (where the best of three tests were recorded) absolute agreement, average measures ICC was calculated; with all other variables absolute agreement, single measures ICC was calculated. Analysis was performed with SPSS V.21 (IBM), Excel V.2016 (Microsoft, USA) and GraphPad Prism V.7 (GraphPad Software, USA).

RESULTS

Participants/cohort

Of a possible 138 participants assessed for eligibility between January 2011 and August 2016, up to 131 were included (figure 1, flow chart). The baseline characteristics are shown in table 4.

Clinical measurements and return to participation

The univariate association with return to participation duration for each of the measures is shown in table 5.

Scatter plots and pooled group estimates for each of the useful clinical measures are presented in figures 2 and 3.

Perceived effort and running speed

Actual running speed (time in seconds as well as average m/s) compared with pooled data for perceived running effort (in deciles) is presented in figure 4. The strength of the association between perceived effort and running speed is seen to improve at higher running speeds/perceived effort, and the overall relation while best described with an exponential (ie, non-linear) curve; however, the additional variance explained over a linear fit was less than 2%.

DISCUSSION

The data presented here allow better understanding of the usual progression of subjective and objective clinical measures during rehabilitation after acute hamstring strain injury and can be a useful adjunct to the clinical reasoning process during rehabilitation. We suggest that the most useful clinical measures are: length of pain on palpation, followed by strength measured in the outer range position (as a per cent of the initial value for the uninjured leg), the Maximal Hip Flexion Active Knee Extension (MHFAKE) Test (expressed as a percentage of the uninjured leg at initial examination) for flexibility and, finally, asking about their pain during daily activities. These four measures are easily clinically applied and are conducted in less than 5 min during routine use. However, we must emphasise that none of these physical measures are optimal—none track perfectly with the progress of rehabilitation or running effort.

While reassessing after interventions and adjusting treatment accordingly is considered a cornerstone of clinical reasoning,¹² we are unaware of any research which investigates the daily subjective and objective measures during rehabilitation. Although clinical criteria for progression throughout the rehabilitation have been suggested, none of these have been validated,¹³ and previous research has looked at isolated clinical features either at initial examination^{14–17} or separated by a week.²

The non-linear association of all of the measures examined here with rehabilitation duration provides support to perform ongoing examination during rehabilitation. A single measure on

Table 3 Intrarater and inter-rater (ICC(2,1), absolute agreement, 'average measures' for the strength tests, 'single measures' for the flexibility tests) for the clinical measures of strength and flexibility along with descriptive data for each variable. For all intrarater measures, the lower bound of the 95% CI was never below 0.80 ('Excellent' reliability²³). For the most part, inter-rater reliability was lower for each measure being 'good' to 'excellent'; however, the 95% CI values were as low as 0.45 ('fair')

	Comparison	ICC (95 CI)	Mean (SD)	Range	Mean (SD)	Day 1	Mean (SD)	Day 2	SEM	MDC	MDC as % of mean	n	p
Intrarater reliability	Inner range (kg)	0.87 (0.84 to 0.89)	22.4 (4.9)	8.0 to 37.7	22.2 (4.9)	22.5 (4.9)	1.78	4.9	22.2	4.9	<0.001	421	<0.001
	Mid-range (kg)	0.89 (0.87 to 0.90)	28.3 (6.1)	8.4 to 48.0	28.2 (6.1)	28.5 (6.1)	2.02	5.6	19.8	5.6	<0.001	570	<0.001
	Outer range (kg)	0.90 (0.88 to 0.92)	33.0 (6.9)	16.8 to 56.2	32.9 (6.9)	33.0 (6.8)	2.19	6.1	18.5	6.1	<0.001	549	<0.001
	SLR (°)	0.88 (0.86 to 0.90)	92.4 (13.6)	0 to 160	92.2 (13.6)	92.7 (13.7)	4.70	13.0	14.1	13.0	<0.001	549	<0.001
	MHFAKE (°)	0.83 (0.80 to 0.86)	82.6 (15.0)	35 to 140	82.2 (15.0)	83.0 (15.0)	6.20	17.2	20.9	17.2	<0.001	537	<0.001
Inter-rater reliability	Inner range (kg)	0.69 (0.45 to 0.83)	20.9 (4.0)	12.7 to 33.8	21.1 (3.6)	20.6 (4.4)	2.01	5.6	26.4	5.6	<0.001	46	<0.001
	Mid-range (kg)	0.83 (0.68 to 0.90)	26.5 (5.6)	18.6 to 41.6	26.6 (5.3)	26.4 (6.0)	1.49	4.1	15.5	4.1	<0.001	46	<0.001
	Outer range (kg)	0.79 (0.62 to 0.88)	30.0 (5.1)	24.8 to 45.6	29.8 (4.7)	30.3 (5.6)	2.17	6.0	20.2	6.0	<0.001	45	<0.001
	SLR (°)	0.74 (0.52 to 0.86)	91.4 (14.7)	67 to 120	91.9 (12.8)	90.8 (16.5)	6.54	18.1	19.7	18.1	<0.001	45	<0.001
	MHFAKE (°)	0.96 (0.92 to 0.98)	83.0 (16.1)	55 to 110	82.6 (16.7)	83.3 (15.6)	3.34	9.3	11.2	9.3	<0.001	25	<0.001

ICC, intraclass correlation coefficient; MDC, minimum detectable change; MHFAKE, maximum hip flexion with active knee extension; SLR, straight leg raise.

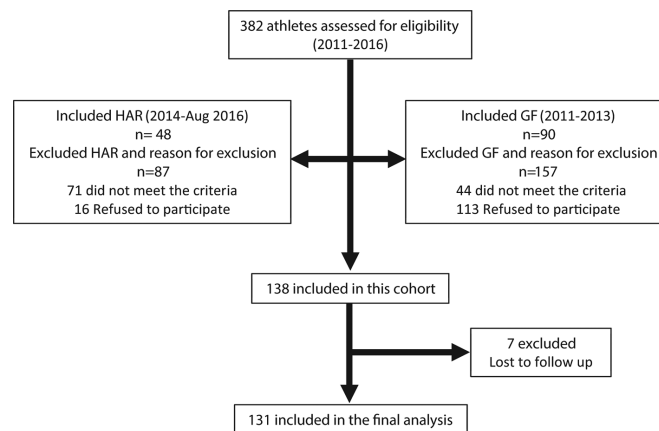


Figure 1 Flow chart for inclusion/exclusion in the study. GF, Growth Factor study; HAR, Aspetar HAMstring Rehabilitation study.

any dimension is unable to describe the magnitude of change for this variable. Two measurements are also unable to describe the rate of change over time when the association is non-linear as seen for all the measures examined here. Previous research on sprinters and dancers¹⁷ has examined the change in different clinical measures over time (2, 10, 21 and 42 days postinjury); however, these values were not adjusted for rehabilitation duration, and it should be noted that at the final (42-day) examination, only 2 of the 33 subjects had returned to sport of these subjects. In that study, subjects returned to sport a median of 16 and 52 weeks (sprinters and dancers, respectively) which makes comparison with this cohort problematic as return to sport time here was a median of 3 weeks for the entire cohort.

Table 4 Demographics for the included athletes (n=131). All values are presented as mean (SD) unless otherwise stated

All athletes (n=131)	
Age (years)	25.9 (5.5)
Height (cm)	176.7 (9.3)
Weight (kg)	74.1 (12.1)
Return to participation duration (days)	23.9 (10.8)
Level of sports, n (%)	
Professional	127 (96.9)
Competitive	4 (3.1)
Type of sports, n (%)	
Athletics	8 (6.1)
Basketball	7 (5.3)
Decathlon	1 (0.8)
Football	93 (71)
Futsal	8 (6.1)
Handball	6 (4.6)
Hockey	4 (3.1)
Physical coach (football)	1 (0.8)
Squash	1 (0.8)
Volleyball	1 (0.8)
Weightlifting and bodybuilding	1 (0.8)
Injury type, n (%)	
Sprinting	84 (64.1)
Non-sprinting	47 (35.9)
Previous hamstring injury, n (%)	
Yes	67 (51.1)
No	64 (48.9)

Table 5 Variance explained is the adjusted R^2 for correlation with percentage of return to participation duration for the individual daily values of each athlete for the specific clinical measure, at each time point in their rehabilitation/running effort. A second-order polynomial was chosen for each measure. All p values for each individual correlation were <0.001 . Note that there were insufficient data available for the inner range measure and running effort

Clinical measure	Variance explained		Variance explained	
	Treatment progression	Number of observations	Running progression	Number of observations
Daily pain (VAS 0–10)	0.29	1056	0.15	112
Length of pain to palpate (cm)	0.18	1043	0.05	110
SLR ROM (% of uninjured leg)	0.29	1086	0.20	111
MHFAKE ROM (% of uninjured leg)	0.29	1035	0.35	110
Inner range (% of uninjured leg)	0.24	1007	Insufficient data	1
Mid-range (% of uninjured leg)	0.27	971	0.31	111
Outer range (% of uninjured leg)	0.27	888	0.34	109

MHFAKE, maximum hip flexion with active knee extension; ROM, range of motion; SLR, straight leg raise; VAS, visual analogue scale.

For practical purposes of tracking progress through rehabilitation, a useful clinical measure would display a large absolute change from the beginning to the end of rehabilitation, and continue changing up to the end of rehabilitation in a linear fashion. The changes in these measures would also need to comfortably exceed the MDC for each given variable. Such a variable would easily allow clinical interpretation and extrapolation, that is, ‘you have improved about 50% in this measure since we started, so we think you are about half-way until RTS.’ Unfortunately, none of the clinical measures examined here met these criteria to our satisfaction. Clinicians should be reminded of the MDC for the strength and flexibility measures when attempting to chart patient progression. In particular, to be 95% sure that a patient has progressed on a particular measure, then the value has to have improved by at least the MDC. While the MDCs for the strength and flexibility measures seen here are similar to previous research,^{18–20} as is usually the case, intra-rater testing mostly showed the smallest MDCs and therefore it is recommended to try to have the same testers perform these measures where possible. We feel this is especially important late in rehabilitation when values are close to 100% and day-to-day

changes are smallest so all opportunities to minimise ‘noise’ in the measures should be taken (ie, use same operator with rigorous attention to technique).

In this cohort, the criteria to join on-field rehabilitation were painlessly performing repeated maximum effort runs, and it is noted that the clinical measures investigated here had typically not fully recovered (100%) at this time.

In this context, both length of pain to palpate expressed as a percentage of the maximum, and outer range strength expressed as a percentage of the uninjured leg are good candidates as they vary from a mean of approximately 80% down to 0%, and 50% up to 100%, respectively, during the course of rehabilitation. In contrast, daily pain measures are seen to essentially normalise after about 30% of the RTS duration, and therefore little change is seen from then until the end of rehabilitation making this measure only useful for the first half of rehabilitation process.

Inspection of the athlete-reported daily pain (figure 2A,E) shows an important limitation of the approach taken here (variance explained) in attempting to quantify the progress of rehabilitation. It can be seen that typically (the median) this value

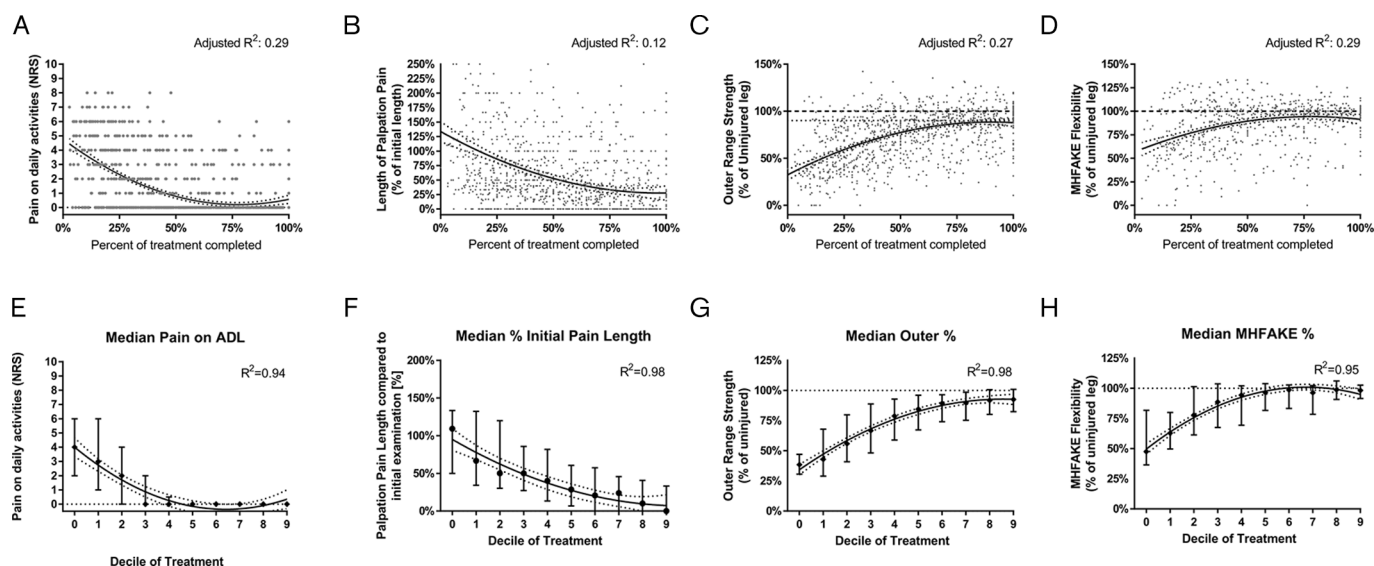


Figure 2 Rehabilitation duration and clinical measures. Individual scatter plots and summarised decile aggregations for average daily pain (A, E), palpation pain length (B, F), outer range strength as a percentage of the uninjured leg (C, G) and MHFAKE as a percentage of the uninjured leg (D, H). The horizontal axes represent the percentage (A–D) or decile (E–H) of rehabilitation duration. In (E–H) the filled circles represent the decile median and the whiskers the associated decile IQR. ADL, activities of daily living; MHFAKE, maximum hip flexion with active knee extension; NRS, numeric rating scale.

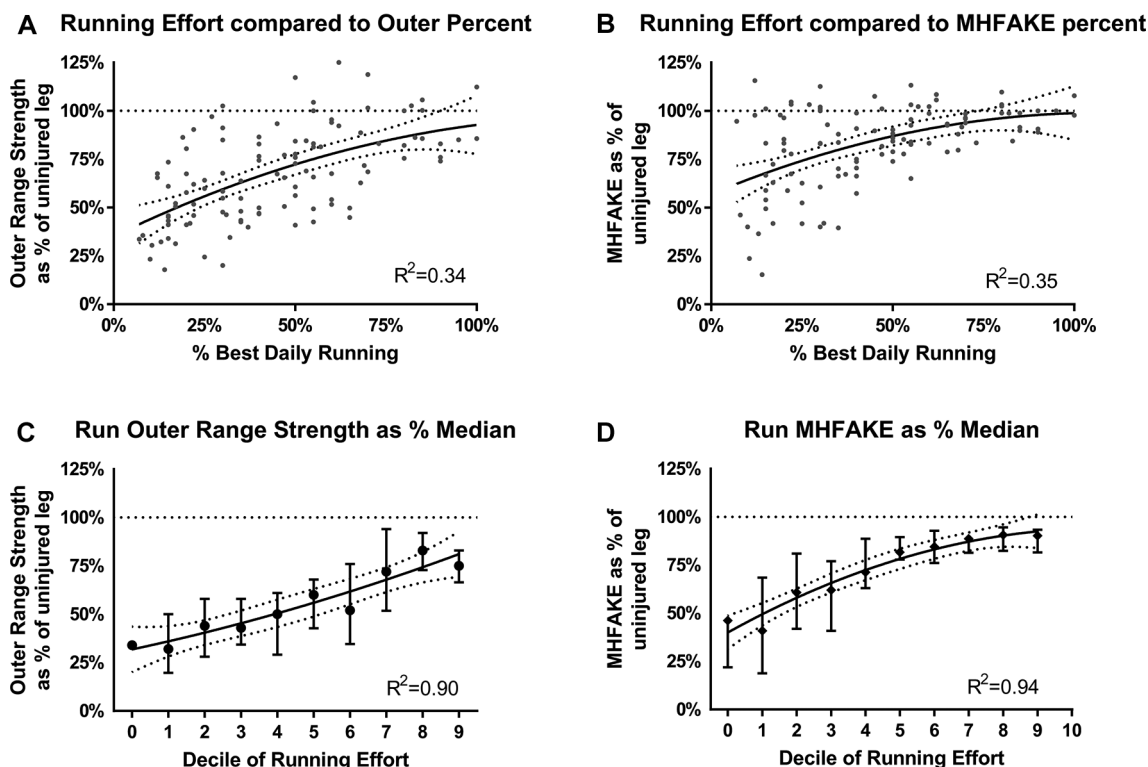


Figure 3 Running effort and clinical measures. Individual scatter plots and summarised decile aggregations for outer range strength as a percentage of the uninjured leg (A, C) and MHFAKE as a percentage of the uninjured leg (B, D). The horizontal axes represent the percentage of best daily running (A, B) or decile of running effort (C, D). In (C, D) the filled circles represent the decile median and associated IQR. MHFAKE, maximum hip flexion with active knee extension.

has dropped to 0 by approximately 30%–40% of the duration of rehabilitation, where this measure remains for the rest of the athlete's rehabilitation. The relatively narrow band of these data, especially during the second half of rehabilitation, allows for a tighter fit for the polynomial line of best fit, hence a higher variance explained. Clinically, however, as this value is not changing for essentially the entire second half of the rehabilitation in most athletes, it is not useful in estimating how far an individual has progressed through rehabilitation. We hasten to add, however, that we do pay great attention to this value on those

rare occasions where athletes report an increase in their daily pain level which we believe is an indication that their session the previous day was excessive in some way.

The three different strength tests used showed differing associations with rehabilitation progression with the 'Outer range' test best reflecting both clinical progression and running effort. It is interesting to note the different relative associations remembering that these strength tests are performed on the same athletes although these findings concur with previous research showing hamstring injured athletes had more marked strength loss when tested in outer range.²¹

Given its common clinical use as a measure of hamstring flexibility, the finding that straight leg raise (SLR) ROM was a less useful clinical indicator is important. Examining the data, we note that relative SLR flexibility is essentially normalised early in rehabilitation with very few subjects showing <90% of the uninjured leg within a few days of commencing rehabilitation. The MHFAKE Test, however, appears to be a more promising clinical indicator varying from approximately 70% of the uninjured leg early up to 100% by the end of rehabilitation.

When examining the strength of association between clinical measures and perceived running effort, strength testing is weakly associated with perceived running effort; however, higher association is seen in the 'outer' range test compared with the 'mid' range test. For logistical reasons, many clinicians are unable to have their injured athletes complete a running programme under their supervision during their rehabilitation session. Therefore, the outer range strength test may serve as a proxy for perceived running ability; however, clinicians should be aware that the associations between these two values are not strong. Ideally, there would be a clinical indicator which was meaningfully and closely associated

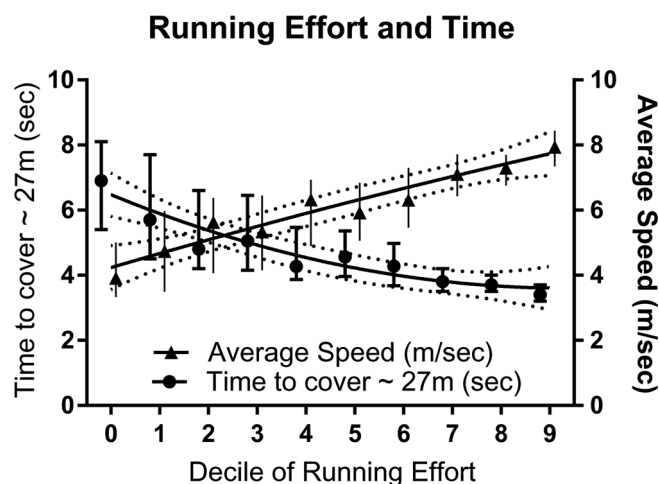


Figure 4 Group median values at each decile of reported running effort (x-axis) and time taken to cover the central 27m of a 30m run (left y-axis) and average speed (right y-axis).

with perceived running effort. This would assist the clinician who is unable to include the running programme during their session to instruct the athletes as to the safe upper limits for perceived running effort to do their running progression unsupervised. This goal remains elusive, and we continue to clinically perform this programme under close supervision.

We found an association between perceived running effort and actual running speed; however, at lower running speeds (less than approximately 40%) the variability is so great as to be essentially clinically meaningless. While not formally examined here, we do note that for a given individual, their ability to reproduce a running speed during different sets and on different days appears to be acceptable. The data here show that the variability between individuals is too great to rely on this as some absolute measure of rehabilitation completion between individuals; however, athletes can be relied on to reproduce their running efforts between sessions.

The other clinical measures considered showed no meaningful association with return to participation duration, and we therefore recommend that these not be considered clinically if information is being sought regarding progression during rehabilitation. Caution is suggested when clinically interpreting results from these (discarded) tests. Alternately, we suggest focusing on the clinical tests identified here (palpation length, outer range strength as a percentage, MHFAKE as a percentage and reported pain when it adversely changes) as being important in influencing the clinician's decisions regarding treatment progression.

Limitations

These findings likely only hold for this population examined which was athletes with an acute hamstring injury who were rehabilitated using our staged criteria-based protocol. It is not known if athletes following a significantly different protocol, athletes suffering a reinjury or chronic hamstring injury would show the same association. It should be noted that none of these measures were perfectly correlated with return to participation duration, and large amounts of interindividual variability are present. These measures cannot be used as strict criteria for predicting RTS, and should only be considered together within an overall clinical reasoning framework. Further, since the analysis here only included univariate analyses, we cannot discount the notion that multivariate analyses could provide more information.

We believe that there is likely a learning effect for the clinicians in establishing rigour around these assessments and would encourage practitioners to invest some time in practising these methods to establish their own reliability. All reliability data presented are for the uninjured leg only and we present no reliability data for the palpation, or the subjective reports of pain. The timing of the running was performed with a handheld stopwatch and is therefore less accurate than, for example, electronic timing.

CONCLUSIONS

One subjective measure and three objective findings tracked relatively well with the progress of rehabilitation in this cohort of athletes with acute hamstring injury, although largely in a non-linear manner. We therefore suggest that these clinical measures can be meaningful to inform the progression of loading during the rehabilitation stages through to return to participation.

What are the findings?

- The best measures to take on your daily examination are to: carefully palpate length of pain, measure outer range strength, then ask about pain, and measure maximum hip flexion with active knee extension (MHFAKE).
- MHFAKE is more useful than straight leg raise to track rehabilitation progress
- Outer range strength seems better than mid-range, which in turn is better than inner range as a strength test measure.
- Athletes can estimate their running effort in a meaningful way, but only above approximately 40% of their perceived maximum.

How might it impact on clinical practice in the future?

Daily assessment of hamstring injured patients should include the identified subjective and objective features only if any useful inferences about treatment progression are being made.

Recommendations

- Palpate length of pain, measure outer range strength, then ask about pain, and measure MHFAKE for your daily examination of hamstring-injured athletes.
- Pain should likely resolve by about a third the way through rehab, so asking about this will be of less use in the second half of rehabilitation unless the pain worsens.
- The MHFAKE seems a better flexibility measure than the SLR to track rehabilitation progress.
- Outer range strength seems better than mid-range, which in turn is better than inner range as a strength test measure.
- Athletes can estimate their running effort in a meaningful way, but only above approximately 40% of their perceived maximum.

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