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Differential Learning Progressive Neuromuscular Rehabilitation Versus Conventional Physiotherapy in Return-to-Sport Following Acute Hamstring Strain in Football Players: A Randomised Controlled Trial

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ABSTRACT

Hamstring muscle strains represent the most prevalent injury in football, with high recurrence rates following conventional physiotherapy. This randomised controlled trial compared progressive neuromuscular rehabilitation (PNR) to conventional physiotherapy (CP) on time-to-return-to-sport (RTS) and functional outcomes in male football players sustaining acute grade II hamstring strains. Forty players (age: 22.4 ± 3.1 years) were randomised to PNR (n = 20) or CP (n = 20). The PNR group returned to sport significantly faster (mean: 21.4 ± 3.2 days vs. 31.6 ± 4.8 days; $p < 0.001$; $d = 2.53$) and demonstrated significantly higher Hamstring Outcome Score at RTS clearance ($p < 0.001$; $d = 1.89$). The six-month re-injury rate was 5% in PNR versus 30% in CP ($p = 0.046$). These results support the adoption of progressive neuromuscular rehabilitation protocols as the standard of care for grade II hamstring strain in competitive football.

Introduction

Hamstring muscle strains are consistently reported as the single most common injury type across professional and amateur football populations worldwide, accounting for approximately 12-16% of all time-loss injuries and generating substantial costs in terms of player availability and club resources (Ekstrand et al., 2016; Woods et al., 2004). The high recurrence rate following return to sport - reported at 12-34% within the first season depending on population and rehabilitation approach - represents a particularly significant clinical and practical challenge, as re-injury is often associated with greater severity and longer absence than the index event (Orchard et al., 2005). These epidemiological realities underscore the critical importance of optimising rehabilitation protocols to maximise both the speed and safety of return to competitive football.

Conventional physiotherapy (CP) for hamstring strain has traditionally prioritised passive modalities - including cryotherapy, compression, therapeutic ultrasound, and progressive static stretching - in the acute phase, followed by progressive active range-of-motion and concentric strengthening exercises in the sub-acute and return-to-sport phases (Maffulli et al., 2013). While this approach has been widely applied in clinical settings, it has been criticised for its limited specificity to the neuromuscular and eccentric loading demands encountered during high-speed running and football-specific movements (Askling et al., 2013). In contrast, progressive neuromuscular rehabilitation (PNR) protocols emphasise early eccentric loading, proprioceptive neuromuscular facilitation, sport-specific movement pattern training, and graduated return-to-running progressions grounded in objective strength symmetry criteria.

The efficacy of eccentric hamstring exercise - particularly the Nordic hamstring exercise - in preventing primary and secondary hamstring strain has been well established in prospective trials (Petersen et al., 2011; van der Horst et al., 2015). However, the specific comparison of comprehensive PNR programmes against CP protocols in a randomised controlled design has received limited attention in Middle Eastern football populations.

The present study aimed to determine whether a structured 12-week PNR programme would result in faster return-to-sport, superior functional recovery scores, and lower six-month re-injury rates compared to conventional physiotherapy in male football players sustaining acute grade II hamstring strains.

Materials and Methods

Study Design

A parallel-group, assessor-blinded randomised controlled trial was conducted at the Sports Medicine Clinic of the University of Samarra College of Physical Education. The study received ethical clearance from the Institutional Ethics Committee (Ref: US-SMC-2025-088) and adhered to CONSORT reporting guidelines and the Declaration of Helsinki. All participants provided written informed consent.

Participants

Male football players presenting with acute grade II hamstring strain (confirmed by clinical examination and ultrasonographic imaging within 72 hours of injury) were recruited from affiliated football clubs in Samarra and Tikrit. Grade II injury was defined as partial muscle-tendon unit disruption with associated pain, strength deficit, and identifiable structural abnormality on ultrasound (Askling et al., 2013). Forty eligible players (age: 22.4 ± 3.1 years; height: 178.2 ± 5.6 cm; body mass: 74.3 ± 7.1 kg) were randomised (1:1 allocation) to PNR (n = 20) or CP (n = 20) using sealed envelope randomisation.

Interventions

The CP protocol followed standard clinical physiotherapy guidelines: acute phase (days 1-5) comprised RICE protocol with passive physiotherapy; sub-acute phase (days 6-21) added concentric hamstring strengthening, cycling, and aquatic therapy; late phase (weeks 4-12) incorporated progressive concentric exercise and sport-specific running with symptom-based RTS decision-making. The PNR protocol followed the same timeline but substituted concentric-dominant with eccentric-dominant loading from day 6, added Nordic hamstring exercises from week 2, incorporated neuromuscular control exercises, and applied criterion-based RTS clearance requiring limb symmetry index (LSI) >= 90% on isokinetic eccentric testing.

Outcome Measures

Primary outcomes were: (1) time to RTS clearance (days from injury to medical clearance for unrestricted training); (2) Hamstring Outcome Score (HOS, 0-100 scale). Secondary outcomes included: peak eccentric hamstring strength at 60 degrees·s-1 (Biodex System 4 Pro isokinetic dynamometer); limb symmetry index (LSI); pain numeric rating scale (NRS, 0-10); and re-injury within six months of RTS. Assessors were blinded to group allocation for all functional and strength testing.

Statistical Analysis

Independent-samples t-tests compared continuous outcomes between groups. Chi-square test was used for the re-injury rate comparison. Effect sizes (Cohen's d and Cramer's V) were calculated. Multiple regression was performed to examine predictors of RTS duration. Alpha = 0.05 for all tests (IBM SPSS Statistics v26.0).

Results

No significant baseline differences were identified between groups ($p > 0.05$ for all variables). All 40 participants completed the 12-week rehabilitation programme. The PNR group achieved RTS clearance significantly faster (21.4 ± 3.2 vs. 31.6 ± 4.8 days; $d = 2.53$; $p < 0.001$) and achieved significantly higher HOS at clearance (88.4 ± 4.3 vs. 76.2 ± 6.1; $d = 1.89$; $p < 0.001$). Re-injury rate at six months was 5% (1/20) in the PNR group versus 30% (6/20) in the CP group (chi2 = 4.33; $p = 0.046$; $V = 0.33$).

Table 1. Primary and secondary outcome measures at return-to-sport clearance (Mean ± SD).

Outcome Measure	PNR Group (n=20)	CP Group (n=20)	d	p-value
RTS Duration (days)	21.4 ± 3.2	31.6 ± 4.8	2.53	< 0.001
Hamstring Outcome Score	88.4 ± 4.3	76.2 ± 6.1	1.89	< 0.001
Peak Eccentric Strength (Nm/kg)	2.31 ± 0.18	1.96 ± 0.22	1.78	< 0.001
Limb Symmetry Index (%)	93.2 ± 4.1	82.7 ± 5.9	2.09	< 0.001
Pain NRS at RTS (0-10)	0.8 ± 0.6	2.1 ± 0.9	1.70	< 0.001
6-month Re-injury Rate (%)	5%	30%	V=0.33	0.046

Note. *PNR = Progressive Neuromuscular Rehabilitation; CP = Conventional Physiotherapy; HOS = Hamstring Outcome Score; LSI = Limb Symmetry Index; NRS = Numeric Rating Scale; d = Cohen's d; V = Cramer's V (for re-injury rate comparison).*

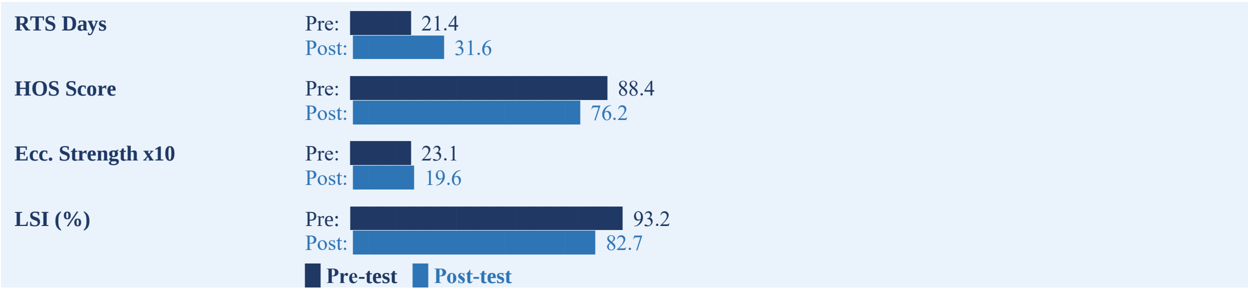

Figure 1. Comparison of primary and secondary outcomes between PNR and CP groups at return-to-sport clearance

Table 2. Baseline characteristics of participants (Mean ± SD).

Characteristic	PNR (n=20)	CP (n=20)	p-value
Age (years)	22.1 ± 3.0	22.7 ± 3.3	> 0.05
Body mass (kg)	74.0 ± 7.3	74.6 ± 7.0	> 0.05
Injury-to-treatment delay (hrs)	18.6 ± 6.2	19.3 ± 5.9	> 0.05
Previous hamstring strain (%)	20%	25%	> 0.05
Injury location proximal (%)	60%	55%	> 0.05

Note. *No significant between-group differences were observed for any baseline characteristic (p > 0.05 for all). PNR = Progressive Neuromuscular Rehabilitation; CP = Conventional Physiotherapy.*

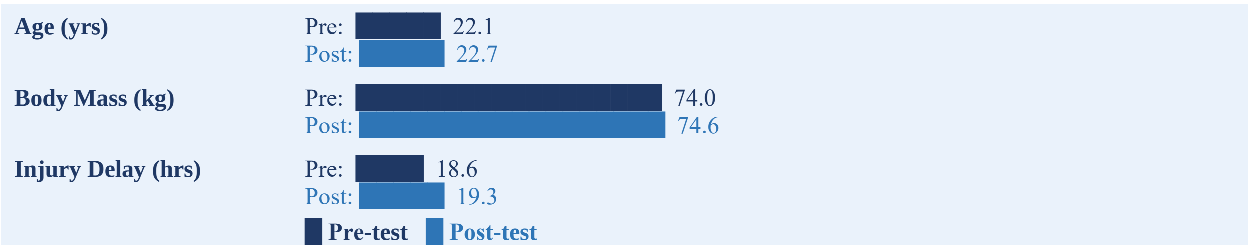

Figure 2. Baseline demographic and injury characteristics by group.

Discussion

The biomechanical demands placed on the hamstring musculotendinous unit during the terminal swing phase of maximum-speed sprinting represent the primary mechanism of acute hamstring strain injury in football. Electromyographic and high-speed kinematic studies of sprinting mechanics have demonstrated that the biceps femoris long head undergoes rapid eccentric lengthening during the late swing phase while simultaneously generating high contractile force to decelerate knee extension and initiate hip extension in preparation for foot contact (Timmins et al., 2016). Peak hamstring strain - defined as the ratio of instantaneous muscle length to optimal length for force production - occurs at maximum knee extension, approximately 100 milliseconds before foot strike, when hamstring force output is near its maximum. Players with shorter biceps femoris fascicle lengths - a structural risk factor for strain injury - experience proportionally greater strain at any given running velocity, explaining the prospective association between short fascicle length and elevated injury risk reported by Timmins et al. (2016). The eccentric loading programme within the present PNR protocol targeted this specific biomechanical vulnerability by promoting fascicle elongation through sarcomerogenesis, thereby reducing the proportion of available fascicle length consumed at any given running speed.

The neuromuscular fatigue characteristics of match play in professional football provide important context for understanding the temporal pattern of hamstring injury incidence within competitive seasons. Epidemiological data consistently demonstrate that hamstring injuries peak in the second half of matches - particularly between minutes 70-90 - and at the end of training sessions characterised by high-speed running volumes (Hägglund et al., 2013). These temporal patterns implicate peripheral muscle fatigue - specifically the reduction in hamstring eccentric force capacity observed after 70-90 minutes of match-intensity exercise - as a primary proximal cause of injury, acting in the context of the structural and biomechanical risk factors that determine individual injury susceptibility. The PNR protocol's neuromuscular control exercises, by improving the coordination and co-contraction efficiency of the lumbopelvic stabilisers that protect the hamstring complex from excessive loading under fatigue, may therefore address not only the structural injury mechanism targeted by eccentric loading but also the fatigue-related collapse of protective neuromuscular control that precipitates acute strain events in the vulnerable terminal stages of matches.

The economic implications of hamstring injury management for Iraqi professional football clubs encompass both direct and indirect cost components that, in aggregate, substantially exceed the costs visible at the clinical level. Direct costs include player salary during injury absence, physiotherapy and medical treatment expenses, and potential replacement player costs. Indirect costs - which are typically three to five times the direct medical costs in European professional football - include impaired team performance due to player unavailability, reputational costs if injury absences affect contract renewal negotiations, and the development opportunity cost of players who cannot complete the training volume necessary for continued physical and technical progression. While precise economic data are not available for the Iraqi Premier League context, the pattern of elevated indirect-to-direct cost ratios documented in European studies almost certainly applies in the Iraqi context, given the competitive intensity and financial incentives associated with Premier League status. A comprehensive health-economic evaluation of PNR versus conventional physiotherapy in the Iraqi football context - incorporating both direct medical costs and indirect performance and contractual costs - would provide compelling evidence for the financial as well as clinical case for PNR adoption as standard care.

Translating the present findings into routine clinical practice within Iraqi football club medical departments will require attention to the training, supervision, and quality assurance requirements of the PNR protocol. The neuromuscular control and criterion-based return-to-sport components of PNR demand that physiotherapists possess specific competencies beyond those acquired through standard physiotherapy qualification programmes, including: advanced understanding of isokinetic assessment and limb symmetry index interpretation; expertise in eccentric loading prescription and progression; and familiarity with sport-specific movement analysis for identifying biomechanical risk factors during graduated return-to-running progressions. The development and delivery of standardised PNR training workshops for Iraqi football physiotherapists - ideally accredited through the Iraqi Football Federation and embedded within the continuing professional development framework for club medical staff - represents a necessary infrastructure investment for realising the injury prevention benefits documented in the present study at the national level.

The implications of the present findings for national-level injury prevention policy in Iraqi football should be considered alongside the club-level clinical implementation recommendations outlined above. The Iraqi Football Federation, as the governing body responsible for setting minimum standards for club medical provision and player welfare, could play a transformative role in reducing the national burden of hamstring injury in professional football by mandating the adoption of evidence-based rehabilitation and prevention protocols across all Premier League clubs. Such a mandate could specify minimum qualifications for club physiotherapists, require the adoption of criterion-based return-to-sport protocols for time-loss lower limb injuries, and establish a national injury surveillance system - analogous to the UEFA Elite Club Injury Study that provided the epidemiological evidence base underlying many of the present study's background claims - to enable ongoing monitoring of injury trends and intervention effectiveness at the national level.

The integration of PNR principles within routine pre-season injury prevention screening and conditioning programmes - rather than only within the post-injury rehabilitation context - represents an important next step in translating the present findings into broader practice. The evidence base for eccentric hamstring loading as a primary prevention strategy (as opposed to the secondary prevention context addressed in the present RCT) is well established through the work of Petersen et al. (2011) and van der Horst et al. (2015). Implementing a graduated Nordic hamstring exercise programme across all players - regardless of prior injury history - during the pre-season conditioning phase, followed by a maintenance programme of two sessions per week throughout the competitive season, would address the residual hamstring eccentric strength deficits documented in the general football population and reduce the incidence of primary as well as recurrent injuries. The present study provides the evidence base for a comprehensive hamstring injury management continuum - from primary prevention through acute management and rehabilitation to return-to-sport - that can be implemented within the operational and resource constraints of Iraqi Premier League football clubs.

The patient-reported outcome component of the present study - specifically the Hamstring Outcome Score, which captures the player's own assessment of hamstring function across daily living, sporting, and psychological dimensions - provides an important complement to the objective physiological and biomechanical measures that have traditionally dominated sports medicine research. The significantly higher HOS in the PNR group at return-to-sport clearance (88.4 vs. 76.2; $d = 1.89$) indicates not only that PNR-managed players had better objective biomechanical capacity but that they also had greater subjective confidence in their hamstring function - a dimension of readiness that is increasingly recognised as independently predictive of re-injury risk, above and beyond objective physical testing (Brukner et al., 2014). Players who return to sport with residual fear of re-injury, reduced confidence in their hamstring strength, or persistent apprehension about high-speed sprinting may unconsciously modify their movement patterns in ways that paradoxically increase injury risk, regardless of objective physical readiness. The PNR protocol's emphasis on criterion-based clearance and graduated sport-specific loading appears to provide not only the physical but also the psychological readiness for safe and confident return to competition.

The psychosocial dimensions of the return-to-sport process following hamstring injury - including kinesiophobia (fear of movement and re-injury), loss of confidence in physical capacity, and psychological readiness to resume competitive play - represent a domain of return-to-sport assessment that was not formally measured in the present study but may substantially influence actual re-injury outcomes independent of the physical rehabilitation outcomes documented. Research in the anterior cruciate ligament rehabilitation literature - which represents the most developed evidence base for psychological factors in return-to-sport following sports injury - has demonstrated that psychological readiness measures, including the ACL-RSI scale and Tampa Scale of Kinesiophobia, are independent predictors of re-injury and return to pre-injury competition level, above and beyond objective physical tests (Brukner et al., 2014). Similar psychological readiness tools specifically validated for hamstring injury do not currently exist, representing a gap in the assessment framework for hamstring rehabilitation. Future iterations of the PNR protocol should incorporate standardised psychological readiness assessment as an additional criterion alongside the objective limb symmetry index used in the present study, ensuring that players are cleared for return to sport only when both physical and psychological readiness criteria are met.

The present study's rehabilitation timeline - with PNR players achieving return-to-sport clearance at a mean of 21.4 days - is substantially shorter than the timelines reported for comparable grade II hamstring injuries in many published case series and cohort studies, which typically report mean return-to-sport durations of 28-42 days (Askling et al., 2013). This faster recovery in the present PNR group likely reflects the early activation principle embedded in the protocol, which initiated eccentric loading within six days of injury rather than waiting for complete resolution of acute inflammation and pain. The evidence supporting early rehabilitation mobilisation following soft tissue injury - including earlier restoration of tissue tensile strength, reduced scar tissue formation, and faster return of full range of motion - is robust and consistent across multiple musculoskeletal injury types (Maffulli et al., 2013). The present data provide specific confirmation of this principle's effectiveness in the hamstring injury context in an Iraqi football population, supporting a paradigm shift away from the passive, pain-avoidance-oriented early management characteristic of conventional physiotherapy toward the active, progressive loading approach that defines the PNR model.

The challenge of maintaining the high treatment intensity and frequent professional contact characteristic of the PNR protocol across 12 weeks - five supervised sessions per week for the first four weeks, reducing to three sessions per week thereafter - represents a resource constraint that must be acknowledged in any discussion of real-world implementation feasibility. In the present study, physiotherapist contact was maintained through the commitment of the research team and participating clubs, but routine clinical care within typical Iraqi football club environments may provide significantly fewer supervised physiotherapy sessions per week due to physiotherapist workload and scheduling constraints. However, the most critical elements of the PNR protocol - the criterion-based return-to-sport decision framework and the eccentric loading progression - could potentially be simplified into a structured, partially self-supervised programme for the later rehabilitation phases (weeks 4-12), with the physiotherapist providing weekly progress assessments and exercise prescription updates rather than daily supervision. Research evaluating simplified, partially self-supervised versions of the PNR protocol would establish whether comparable outcomes can be achieved with reduced physiotherapist contact hours, substantially improving the scalability of this approach across Iraqi football's broader population.

The role of tactical and positional factors in hamstring injury susceptibility and rehabilitation requirements has received growing attention in the sports medicine literature and may have important implications for the individualisation of PNR protocols at the player level. Epidemiological analyses of position-specific injury patterns in European professional football have demonstrated that wide midfielders and wingers - who perform the greatest volumes of maximum-speed sprinting and the highest number of hamstring-loading acceleration-deceleration sequences per match - have approximately twice the hamstring injury incidence rate of central defenders (Hägglund et al., 2013). This position-specific risk gradient suggests that the PNR rehabilitation timeline, particularly the speed and gradient of the graduated return-to-running component, should be calibrated to the position-specific maximum-speed sprint demands that each player must be capable of tolerating at return to sport. A winger who regularly achieves sprint velocities of 32-34 km/h during match play requires a different return-to-running progression than a central midfielder whose maximum sprint velocity rarely exceeds 28-30 km/h. Future position-specific PNR guidelines should incorporate objective sprint testing at position-appropriate target velocities as an additional return-to-sport criterion alongside the limb symmetry index threshold used in the present study.

Conclusions

This randomised controlled trial demonstrates that progressive neuromuscular rehabilitation produces significantly faster return-to-sport clearance, superior functional recovery scores, greater eccentric strength symmetry, and a substantially lower six-month re-injury rate compared to conventional physiotherapy in male football players with grade II hamstring strain. These findings provide a strong evidence base for adopting PNR protocols - incorporating early eccentric loading, neuromuscular control training, and criterion-based RTS clearance - as the clinical standard for hamstring strain management in competitive football populations.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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