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Practices and perceptions in hamstring training for injury risk mitigation: A survey-based mixed-methods analysis

Steven Ross[1], Nicholas J Ripley[1], John J McMahon[1,2], and Paul Comfort[1,3]

GQ1

GQ2 **Abstract**
GQ4 GQ5 In this study, the practices and perceptions of sport and exercise practitioners regarding hamstring training for injury risk mitigation were investigated. Hamstring strain injuries (HSIs) remain a prevalent issue across sports, despite extensive research. An anonymous survey was conducted to assess how practitioners integrate evidence-based strategies, such as the Nordic hamstring exercise (NHE) and high-speed running (HSR), into their training programmes. The survey included both fixed-response and open-ended questions, enabling a mixed-methods analysis of training approaches. A total of 47 practitioners responded, revealing that most incorporate the NHE and HSR into both in-season and off-season training. However, there were notable differences in volume, with higher HSR distances and NHE volumes programmed in the off-season. Despite widespread adoption of the NHE, practitioners indicated that the volumes of NHE used are still likely higher than the smallest effective dosages reported in the literature. Thematic analyses highlighted several key challenges practitioners face, including athlete compliance with training programmes, multi-disciplinary team coordination, and time limitations. Practitioners emphasised the importance of exposing athletes to maximal running efforts to reduce HSI risk, while also integrating strength training exercises that target the hamstrings. The study serves to highlight a need for further improvements in communication among teams and better athlete education which could enhance the effectiveness of hamstring training programs. Additionally, the findings of the current study indicate a need for future studies that explore the combined effects of resistance training and HSR, as well as how scientific recommendations can be more effectively implemented in practical settings.

Keywords
Resistance training, high-speed running, sprinting, muscle injury, athletic development

Introduction

Hamstring strain injuries (HSIs) are common across various sports, but there is no consensus on training approaches to reduce injury risk. Research by Weldon et al.[1–3] on strength and conditioning practices in soccer, cricket and volleyball, highlights limitations including, limited athlete contact time, facilities, and equipment. Freeman et al.[4] surveyed elite Australian rules football (AFL) coaches, revealing disparities in global positioning system (GPS) usage for sprint monitoring and in the definitions of high-speed running (HSR) and sprint velocities. While epidemiological data on HSI exist across sports, little is known about practitioners' training practices, which are crucial for understanding injury epidemiology and prevention.

Despite a surge in HSI-related research over the past 15 years, there is little evidence of a reduction in HSI incidence. In fact, there may be an increase.[5,6] Some authors suggest that HSI risk mitigation protocols are not applied in practice.[7] Thus, understanding real-world practices and practitioners' rationale is essential to grasp how approaches differ across sports, regions, and practitioners.

Bahr et al.[7] surveyed UEFA Champions League and Norwegian Tippeligaen practitioners, finding that evidence-based guidelines for the Nordic hamstring exercise (NHE)

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were not adopted in elite soccer. Specifically, the 10-week NHE protocol by Mjølsnes et al.,[8] which involves high volumes (up to 90 repetitions per week), was not used, likely due to its substantial time commitment. Cuthbert et al.[9] found that lower NHE volumes (~8 repetitions per week) over ≥6 weeks effectively increased knee flexor strength and fascicle length (FL), comparable to higher volumes and longer protocols. This lower volume is more appealing to practitioners and mitigates issues like delayed onset of muscle soreness (DOMS).

Mjølsnes et al.[8] recorded muscle soreness on a 0–10 scale during their program and found no scores above 3/10, suggesting DOMS may not be as significant a barrier as perceived. Additionally, their program had a 96% compliance rate among Norwegian University football players, though this might not be realistic for elite athletes with higher technical and tactical training volumes and competitive schedules. Ripley et al.[10] showed that interventions positively impact HSI incidence with ≥50.1% compliance and consistent sessions every ≤3 weeks, suggesting positive outcomes with low training volume and frequency. While Bahr et al.[7] provided insights into applied practices and Weldon et al.[1–3] broadened understanding in several sports, there remains a gap in understanding how recent scientific developments translate into practice. Existing HSI literature often lacks ecological validity, focusing on single exercises (like NHE) in isolation rather than within holistic training programs. Understanding how exercises are integrated into broader training can inform future training intervention studies and enhance practice.

To address this gap, examining how current practices reflect scientific advances and their effectiveness in real-world settings is crucial. It is also important to investigate whether practitioners adopt new evidence-based protocols and how they tailor these to specific sports, athlete needs, and logistical constraints. This understanding can help bridge the gap between research and practice, ensuring that training interventions are both scientifically grounded and practically feasible.

The aim of this study was to survey practitioners to collate a more detailed overview of the applied practices specifically focused on the mitigation of HSI risk. It was hypothesised that practitioners would use lower volumes of the NHE than advocated by Mjølsnes et al.[8] but that the NHE would be used in conjunction with other hamstring resistance training methods. It was hypothesised that HSR would be programmed by practitioners at likely higher volumes during the off-season than in-season. It was also hypothesised that practitioners would refer to limiting factors such as DOMS as barriers to implementation of resistance training in their practice.

Methodology

The study used an anonymous online survey to investigate the practices and perceptions of hamstring training in relation to HSI prevention and enhanced athletic performance among sport and exercise practitioners. The survey was developed using the open-access survey application 'Google Forms'. The survey was presented in English language only and was comprised six subsections: (a) written informed consent; (b) professional profile; (c) off-season training practices; (d) in-season training practices; (e) approaches to testing and training; and (f) training and testing philosophy. While the full details of the survey can be found in SUPPLEMENTARY FILE A, the survey covered (not including informed consent questions) 27 fixed-response questions which included Likert scale, multiple choice and 'all that apply' style questions and 21 open-ended questions, intended to allow participants to provide a qualitative rationale or underpinning philosophy to their responses.

The survey was advertised on social media, which included an access link to the participant information sheet and informed consent. Participants were required to confirm that they provided informed consent in order to access the full survey.

47 practitioners responded to the survey. All descriptive data regarding the profile, including age, sex, field of practice, qualification level and accreditation status of the responders is presented in SUPPLEMENTARY FILE B. As some aspects of the professional profile allowed for multiple responses, such as sports worked in, qualifications held, accreditations held and typical job role and responsibilities, those sections have been expanded to include all responses, resulting in total exceeding 47 responses.

Inclusion criteria for participation were any practitioner working with athletes in which a specific focus of their training was the reduction of risk factors associated with HSI and/or hamstring training with the aim of enhancing athletic performance. Given the diverse range of qualifications, job titles, and accreditations across the globe, the survey did not aim to recruit any one specific practitioner.

All survey responses were exported from Google Forms to Microsoft Excel for coding of responses. Fixed response questions were analysed using frequency analysis in Jamovi (version 2.2.5). Differences in weekly NHE repetitions were calculated using two separate paired samples t-tests to compare (a) the upper limit of weekly NHE repetitions and (b) the lower limit of weekly NHE repetitions identified by practitioners. This was due to the Likert-style nature of the questions pertaining to the number of sessions, sets, and repetition structures typically used by practitioners. For instance, if a practitioner stated that they typically programme 1–2 weekly sessions consisting of 3–4 sets of 3–4 NHEs, the upper end of weekly session volume was calculated as 2 weekly sessions of 4 sets of 4 NHE repetitions ($2*4*4 = 32$ weekly NHEs) whereas, the lower end was calculated as $1*3*3 = 9$ weekly NHEs. Prior to the paired samples-tests, assumptions of equal variances were checked and assumed through the Levene test for homogeneity of variance using IBM SPSS (version 25). The same process of analysing upper and lower limits of weekly training repetitions was followed for non-NHE-based resistance training exercises. Magnitude of effect between off-season and in-season weekly resistance training repetitions was calculated and presented using https://estimationstats.com[11] with magnitude of difference expressed as Hedges' g given the unequal number of responses between off-season and in-season. Magnitude of effect was interpreted on the following scale[12]: *trivial* ≤0.19; *small* 0.20–0.59; *moderate* 0.60–1.19; *large* 1.20–1.99; *very large* ≥2.00.

Open-ended questions were analysed using a six-staged thematic analysis as described by Braun and Clarke.[13] The stages included: (1) familiarisation with data; (2) generating initial codes; (3) searching for themes; (4) reviewing themes; (5) defining and naming themes; (6) producing the report. Stages 2–6 of the thematic analyses were conducted in NVivo 12 Plus for Windows (QSR International).

Results

HSR practices

Of those who reported programming HSR sessions during the off-season, 23 provided an indication of the approximate total HSR session distance covered during a typical off-season session for their athletes. Of the 23, 56.5% (N = 13) stated that the typical total session distance covered at HSR would be 100–500 m with 21.7% (N = 5) of responders programming session distances of 500–1000 m and 17.4% (N = 4) and 4.3% (N = 1) programming session distances of 1000–1500 m and ≤100 m, respectively.

Table 1

All Sports Scientists, Sports Rehabilitators, and the Athletic Therapist reported that they prescribe HSR sessions during the competitive season, whereas 78.6% (N = 11) 70% (N = 7) and 94.1% (N = 16) of Sports Therapists, Physiotherapists, and Strength and Conditioning coaches reported prescribing in-season HSR sessions, respectively.

23 of the responders provided an approximation of the typical programmed session HSR distances in-season, of which 65.2% (N = 15) of practitioners programmed a typical session distance between 100–500 m, with 28.1% (N = 6) programming session distances of 500–1000 m, with one S&C coach programming session distances of 1000–1500 m for senior AFL athletes. One Sports Therapist indicated session distances >1500 m with professional soccer players; however, this was noted as 'total', so it is possible that this is accumulative over conditioning and sport-specific sessions.

Of those who programme HSR sessions as part of their current role, 16 practitioners did not provide a numerical approximation of HSR session distances during the off-season and 17 did not provide numerical HSR session distances in-season. Thematic analysis of the descriptions of these non-numerical responses indicated that during the off-season practitioners tend to give more emphasis on speed preparation and drills with a specific focus on acceleration and deceleration. Response themes also focused a greater volume of HSR or frequency of HSR exposures during the week in comparison to in-season practices. Several practitioners indicated that they focus on approximately 3–6 maximal efforts or efforts building to maximal velocity in-season, whereas several practitioners indicated approximately 4–10 efforts during the off-season. While HSR weekly frequencies and the thresholds for identifying HSR are reported later in this paper, there was a clear thematic trend to the utilisation of lower intensity bouts during the off-season with practitioners indicating that 'HSR' sessions may include bouts of 50–75% of maximal

AQ2 **Table 1.** XXXX.

	Profession							
	Session HSR Distance (m)	Strength and Conditioning Coach	Sports Therapist	Sports Scientist	Physiotherapist	Athletic Therapist	Sports Rehabilitator	Total
Off-season	≤100	1	-	-	-	-	-	1
	100–500	4	3	1	4	-	1	13
	500–1000	4	-	-	1	-	-	5
	1000–1500	2	1	-	-	-	1	4
	Session HSR Distance (m)							
In-season	100–500	7	4	1	2	-	1	15
	500–1000	4	-	-	1	-	1	6
	1000–1500	1	-	-	-	-	-	1
	>1500	-	1	-	-	-	-	1

velocity, with some practitioners identifying that they still ensure a minimum dose of two efforts exceeding 90% of maximal velocity or maximal effort. On the other hand, in-season HSR sessions were more associated with practitioners indicating bouts exceeding 80% of maximal velocity or maximal effort.

Furthermore, there was an indication of programming HSR sessions based on individual match-play demands. For instance, one practitioner identified that they aim to ensure that athletes do not exceed 80% of their match-day HSR volume during in-season training whereas another indicated that their HSR volume would approximate 20% of the athlete's match-day HSR exposure. Regarding the off-season two practitioners also highlighted that HSR sessions would be programmed to approximately 10–20% of total match-play HSR exposures.

Table 2

During the off-season, of the 41 responders that programmed HSR sessions, 75.6% (N = 31) programmed 1–2 sessions per week, with 14.6% (N = 6) programming 3–4 weekly sessions, with the remaining 9.8% (N = 2) distributed equally between 0–1 and 2–3 sessions per week.

A very similar trend was observed with regards to in-season, 78.0% (N = 32) of practitioners that programmed HSR sessions, programmed 1–2 weekly sessions, with 14.6% (N = 6) programming 3–4 weekly sessions and 4.9% (N = 2) and 2.4% (N = 1) programming 2–3 and 0–1 weekly sessions, respectively.

When questioned what practitioners considered as 'high-speed' during programmed HSR sessions, all of those that stated that they do programme sessions, identified a target which they would use for high-speed, however there was a mixture of specific velocity thresholds and perceived intensities. For those using specific HSR velocity thresholds, all indicated a minimum of 5.5–6 $m{\cdot}s^{-1}$ (19.8–21.6 $km{\cdot}h^{-1}$) with sprinting velocities between 7.5–8 $m{\cdot}s^{-1}$ (27.0–28.8 $km{\cdot}h^{-1}$). On the other hand, those that indicated the use of a perceived intensity, such as a percentage of maximal, there was more variability with some practitioners indicating values as low as 50–75% of maximal, but largely practitioners seemed to advocate the use of perceived thresholds of ≥85% of maximal effort.

Table 3

From all responders, it was identified that only six professionals indicated that they do not collect any objective data from HSR sessions. While four of these participants identified that they do not actively lead HSR sessions in their current job role, two practitioners (one Sports Scientist and one Strength and Conditioning Coach) identified that they do lead HSR sessions within their role, but do not collect objective data from the session. Across all professions other than the single Athletic Therapist, it was clear that the majority of practitioners obtain more than one source of objective data from their HSR sessions, with total sessions distance, GPS derived velocities and/or accelerations and athlete perceived intensity as the most commonly utilised methods.

When asked '*how would you best describe the primary focus of your high-speed running sessions?*', 43 practitioners responded, which included three practitioners which had not previously stated that they run HSR sessions, however during analysis of these responses there was limited information provided such as 'football conditioning', 'to meet demands of sport' and a slightly more detailed response of 'to offer a stimulus similar to that of maximal match-day exertion'. As these three practitioners had not previously stated they programme or lead HSR sessions or indicated a response in questions pertaining to session volume or frequency, it is unclear whether the information provided was a general overview of what they consider to be an important focus of HSR training, or if they were referring to their approach to HSR training during

Table 2. XXXX.

		Profession					
	Weekly HSR Exposure (off-season)	**Strength and Conditioning Coach**	**Sports Therapist**	**Sports Scientist**	**Physiotherapist**	**Sports Rehabilitator**	**Total**
Off-season	0–1	2	-	-	-	-	2
	1–2	9	9	2	9	2	31
	2–3	1	-	1	-	-	2
	3–4	5	1	-	-	-	6
	Weekly HSR Exposure (off-season)						
In-season	0–1	-	-	1	-	-	1
	1–2	14	9	-	7	2	32
	2–3	2	-	-	-	-	2
	3–4	1	1	2	2	-	6

Table 3. XXXX.

Data Obtained on HSR Sessions	Strength and Conditioning Coach	Sports Therapist	Sports Scientist	Physiotherapist	Sports Rehabilitator	Athletic Therapist	Total
Session distance	14	10	-	2	5	1	32
Perceived Intensity	10	8	1	1	4	-	24
None	1	3	-	1	1	-	6
Velocities/Accelerations (global positioning system [GPS] derived)	11	5	-	2	4	1	23
Velocities/Accelerations (timing gate/timing derived)	4	2	-	-	4	1	11

Table 4. XXXX.

	Profession						
Time Between HSR Sessions	Strength and Conditioning Coach	Sports Therapist	Sports Scientist	Physiotherapist	Athletic Therapist	Sports Rehabilitator	Total
24 h	1	1	-	-	-	-	2
36 h	2	3	-	-	-	-	5
48 h	12	7	3	3	1	2	28
72 h	-	1	-	3	-	-	4
>72 h	-	-	-	1	-	-	1

rehabilitation as the responses were provided by two Physiotherapists and one Sports Therapist.

Of those practitioners that had previously indicated that they programme and/or lead HSR sessions, the overwhelming theme pertaining to the primary focus of HSR sessions was to 'build capacity', 'provide exposure to maximal running efforts' and to 'reduce injury risk'. Further, there was a common theme of combining technical coaching cues relating to front side mechanics, technical proficiency and either mimicking or preparing the athlete for the volume of HSR efforts they would typically be exposed to during match-play. To a lesser extent, there was also reference made from some practitioners to exposing the athlete to multidirectional movements, external cues, and a competitive environment within the session.

Table 4

With regards to the typical time period between HSR sessions, 39 practitioners provided a numerical approximation, with 71.8% (N = 28) of practitioners indicating that they allow 48 h between HSR sessions. four practitioners provided a non-numerical description of their typical approach, with one practitioner indicating that the timeframe can vary between 24–36 h, given that not all sessions target maximal speed, indicating that Wednesday sessions generally focus on 'lactate work and moderate intensity interval training', with Thursday focusing on top speed and Friday focusing on 'low level' aerobic training. One further practitioner indicated that the time-period was typically 48 h, but that they tend to time short sprints to establish 'readiness'. The same practitioner also identified that they use these times to establish whether the athlete is ready for intense training on that day but did not identify a specific threshold which the athlete would be required to achieve to be considered ready for intense training exposure. One S&C coach working with AFL athletes indicated that timing of HSR sessions which focus on >80% maximal velocity with a focus on reduction of HSI risk are usually positioned around match day minus three or four.

Resistance training practices

From the 41 practitioners who identified that they programme and / or lead hamstring focused resistance training sessions during the off-season, 80.5% (N = 33) stated that they would typically include 1–2 sessions per week. The remaining 19.5% (N = 8) reported a higher weekly training frequency of 3–4 sessions. From the 19.5% (N = 8) stating that they programme and / or lead 3–5 resistance training sessions per week, all but one of them worked in intermittent intensity-based team sports, with one working in athletics and combat sports.

Table 5

The typical off-season set and repetition schemes for the NHE varied among practitioners, with no clear pattern of approach between professions. Therefore, frequency

Table 5. XXXX.

		Profession						
	Weekly Resistance Training Sessions	**Strength and Conditioning Coach**	**Sports Therapist**	**Sports Scientist**	**Physiotherapist**	**Athletic Therapist**	**Sports Rehabilitator**	**Total**
Off-season	1–2	13	8	2	8	-	2	33
	3–4	4	2	1	1	-	-	8
	Weekly Resistance Training Sessions							
In-season	1–2	15	10	3	7	-	2	37
	3–4	1	-	-	-	-	-	1
	5–6	-	1	-	2	1	-	4
	6–7	-	1	-	-	-	-	1

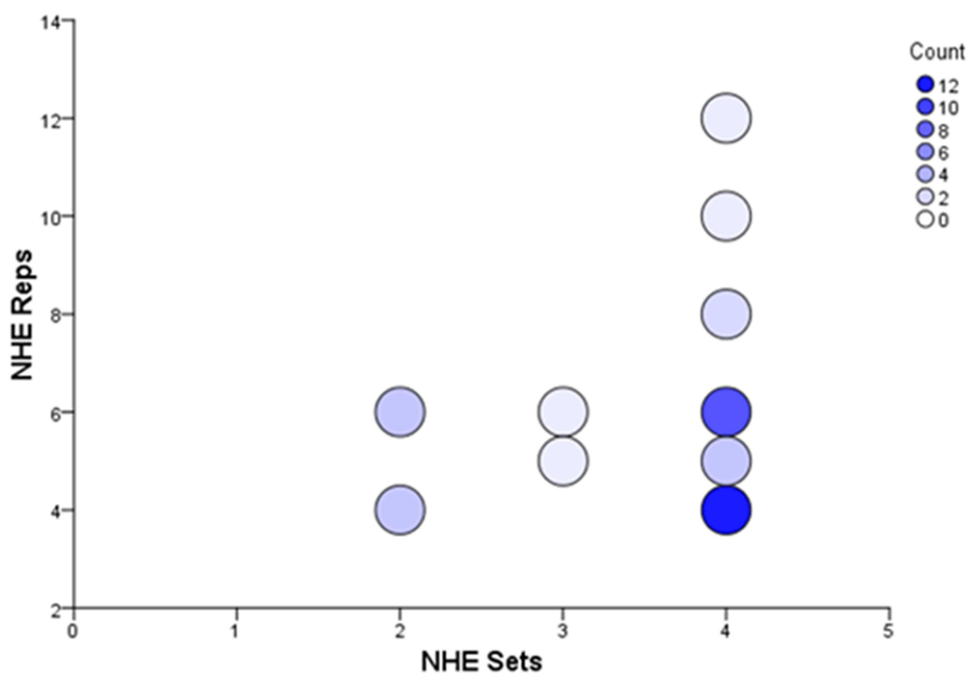

Figure 1. A binned scatterplot displaying the frequency counts for repetition (vertical axis) and set (horizontal axis) schemes when programming the NHE during the off-season. The lightest grey shading denotes the fewest counts (two) through to the darkest shaded blue denoting the highest number of counts (twelve).

counts of typical set and repetition schemes are displayed in Figure 1 with the highest count of 12 practitioners selecting an approach of four sets of four repetitions, followed by 10 counts of four sets of six repetitions. It is clear that most practitioners seem to adopt schemes based on four sets, however eight practitioners did identify that they adopt lower set schemes ranging from two sets of four repetitions to two sets of six repetitions. At the upper end of the scale, one practitioner identified the use of four sets of ≥12 repetitions of the NHE. It should be noted that the questions in the survey pertaining to NHE repetitions and sets were presented on a Likert-type scale, in which practitioners could select a small range e.g., 1–2 sets, 3–4 sets, 5–6 sets and likewise for repetitions. Practitioners could also select an option of 'other' and provide a more detailed response if they felt that the scaled options did not best represent their typical practice. Therefore, for brevity in presentation, the data points presented represent the upper end of the scale for each practitioner response. Some practitioners provided some additional qualitative information here for instance one practitioner identified that their typical approach is 1–2 sets, but some athletes may increase to three sets, while another stated that they take a progressive approach to programming the NHE over a six-week period starting with 3–4 sets of four repetitions. Finally, one practitioner did not provide an indication of set and repetition structure but did indicate that their NHE programming is informed by isokinetic testing, but unfortunately did not elaborate further on this statement.

91.5% (N = 43) of practitioners identified that they programme and / or lead in-season hamstring focused resistance training programmes which consisted of 94.1% (N = 16) of Strength and Conditioning Coaches, 85.7% (N = 12) of Sports Therapists, all Sports Scientists (N = 3), Sports Rehabilitators (N = 2) and the single Athletic Therapist and 90% (N = 9) of Physiotherapists.

Of the 43 practitioners that programme / lead in-season resistance training sessions, 86.0% (N = 37) identified that they typically include 1–2 weekly sessions. This indicates a small reduction in resistance training frequency from the off-season, from 19.5% (N = 8) of practitioners including 3–4 weekly sessions in the off-season, down to 14.0% (N = 1) in-season, however the use of the 'other' option with reference to in-season, meant that all responses >2 weekly sessions, included the possibility of three or more sessions, which may indicate variance in training practices in-season likely due to fixture cycles, given that most of the practitioners that indicated three or more sessions worked in soccer in the United Kingdom, which can have large variations fixture congestion, particularly during the winter months.[14]

The typical repetition and set structures when programming the NHE in-season were largely varied (Figure 2) across practitioners, with two sets of four repetitions and four sets of four repetitions highlighted as the most common responses (10 counts each). However, as these set and repetition structures are presented as the upper end of practitioner responses, the weekly NHE repetitions (sessions*sets*repetitions) for the upper and lower end of practitioner responses are presented in Figures 3 and 4, respectively.

The upper-end of the number of weekly NHE repetitions during the off-season and in-season are presented in Figure 3. There was a small but non-significant (g = -0.44; p = 0.100) difference between the mean number of off-season (45.5 ± 23.4 weekly NHE repetitions) and in-season (37.5 ± 25.5 weekly NHE repetitions).

Furthermore, when considering the lower end of the typical weekly NHE repetitions reported by practitioners, differences in weekly repetition volume was also small but not statistically significant (g = -0.42; p = 0.140 decrease in the number of weekly NHE repetitions in-season (12.7 ± 12.3 weekly NHE repetitions) compared with off-season (17.3 ± 12.2 weekly NHE repetitions).

Practitioners were asked to identify any resistance training exercises they use excluding the NHE. A full list of exercises identified is available in Supplementary File C.

With regards to the lower end (Figure 5) of typical weekly repetitions of non-NHE resistance exercises between off-season and on-season, there was a small, but non-significant (g = -0.55; p = 0.073) reduction in volume in-season (18.94 ± 11.74 weekly non-NHE repetitions) compared with off-season (27.71 ± 22.07 weekly non-NHE repetitions).

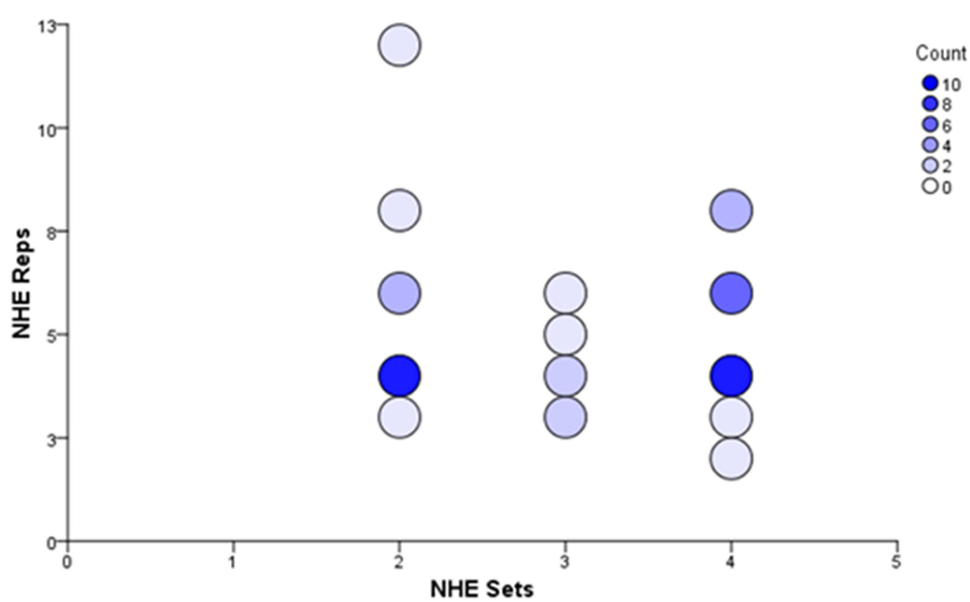

Figure 2. A binned scatterplot displaying the frequency counts for repetition (vertical axis) and set (horizontal axis) schemes when programming the NHE in-season. The lightest grey shading denotes the fewest counts (two) through to the darkest shaded blue denoting the highest number of counts (ten).

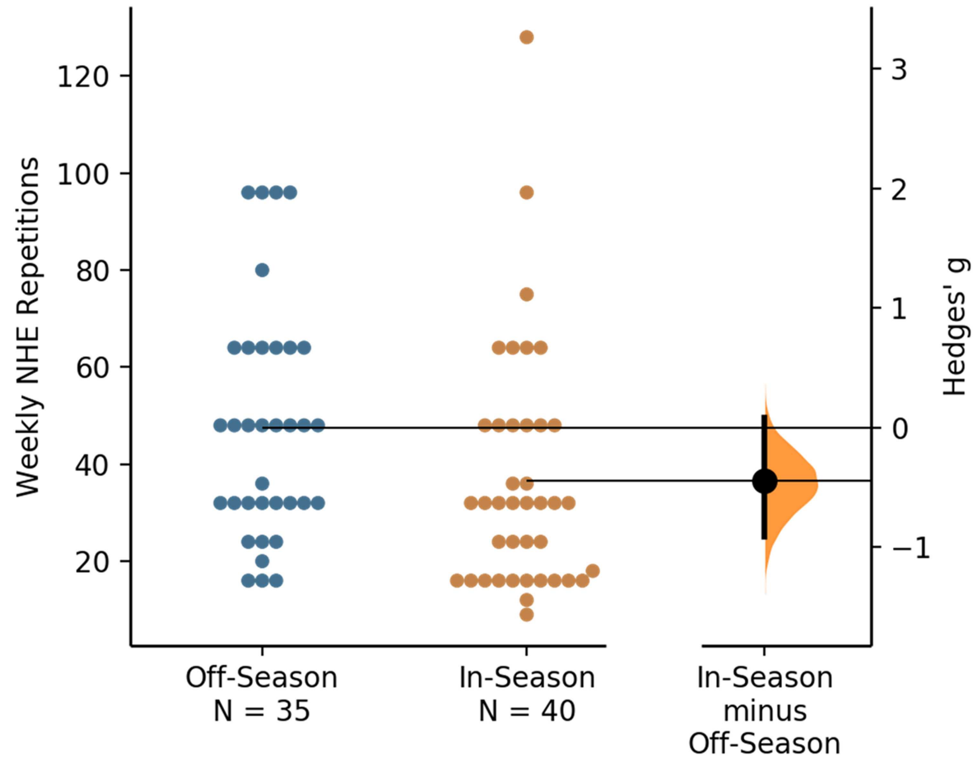

Figure 3. A Gardner-Altman estimation plot illustrating the upper end of weekly number of NHE repetitions during the off-season (blue) and in-season (orange). Both groups are plotted on the left axes, with the mean difference and magnitude of difference are plotted on floating axes on the right. The mean magnitude of difference is depicted as a black dot, with the 95% confidence interval indicated by the ends of the vertical bar.

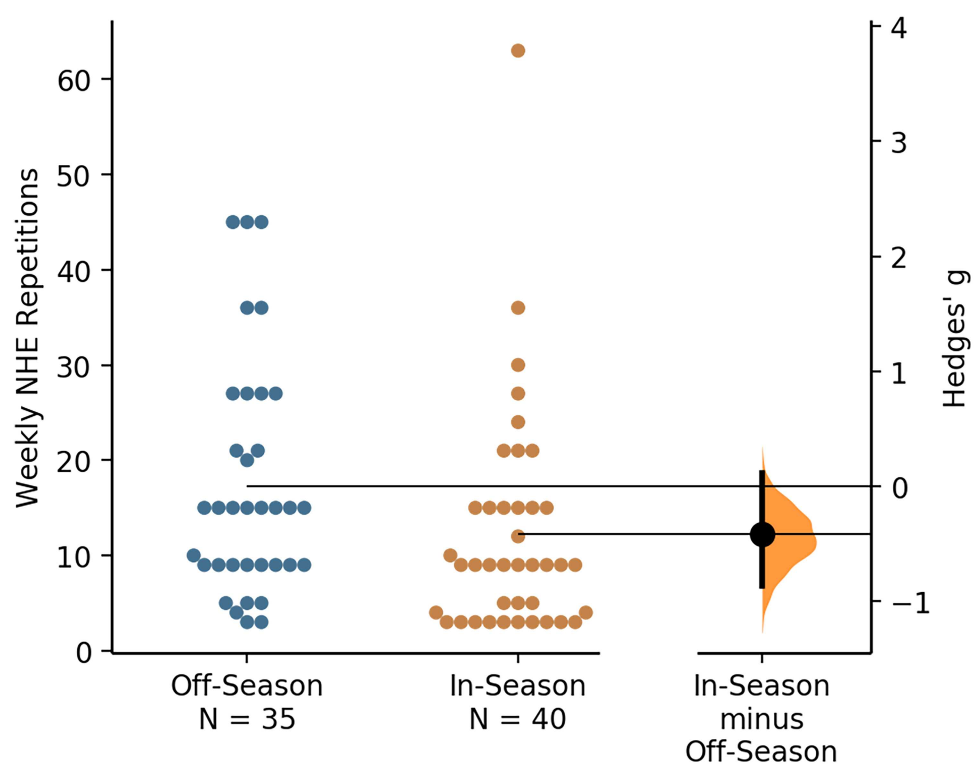

Figure 4. A Gardner-Altman estimation plot showing the lower end of weekly number of NHE repetitions offseason (blue) and in-season (orange). Both groups are plotted on the left axes, with the mean difference and magnitude of difference are plotted on floating axes on the right. The mean magnitude of difference is depicted as a black dot, with the 95% confidence interval indicated by the ends of the vertical bar.

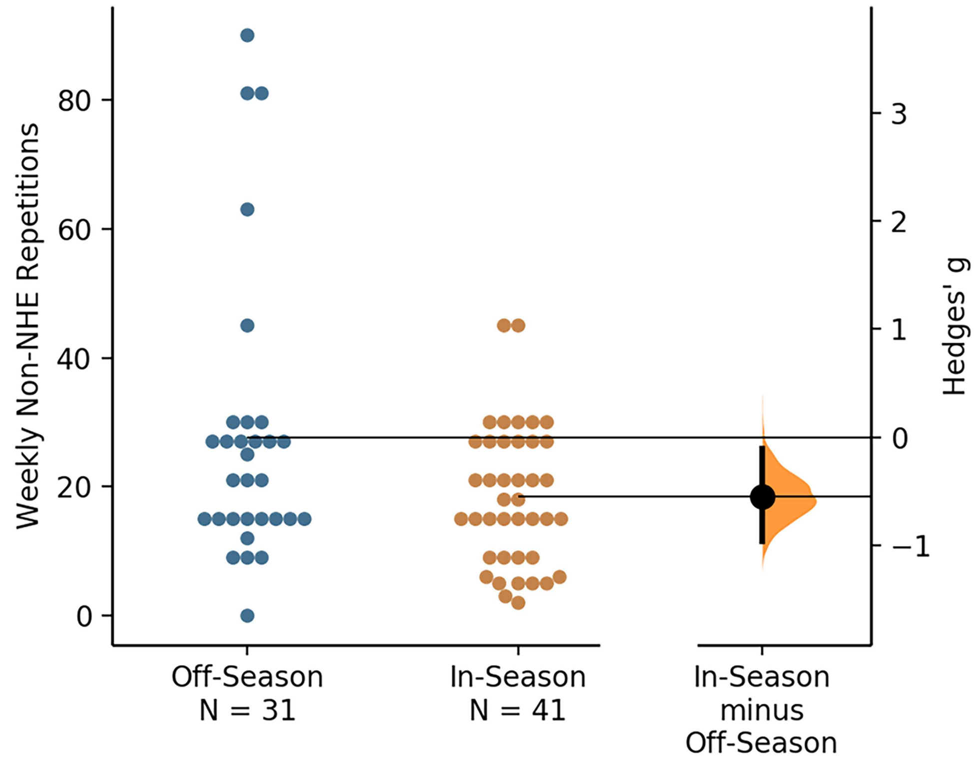

Figure 5. A Gardner-Altman estimation plot showing the lower end of weekly number of non-NHE repetitions off-season (blue) and in-season (orange). Both groups are plotted on the left axes, with the mean difference and magnitude of difference are plotted on floating axes on the right. The mean magnitude of difference is depicted as a black dot, with the 95% confidence interval indicated by the ends of the vertical.

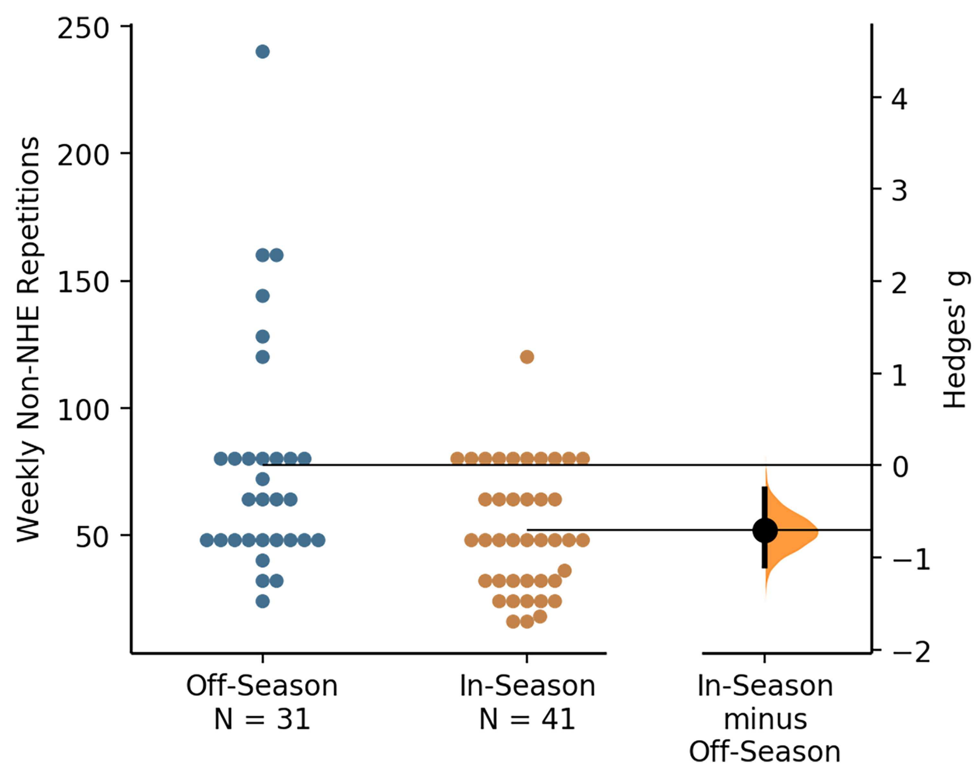

Figure 6. A Gardner-Altman estimation plot showing the upper end of weekly number of non-NHE repetitions off-season (blue) and in-season (orange). Both groups are plotted on the left axes, with the mean difference and magnitude of difference are plotted on floating axes on the right. The mean magnitude of difference is depicted as a black dot, with the 95% confidence interval indicated by the ends of the vertical.

When considering the upper end (Figure 6) of the reported typical weekly non-NHE resistance training repetitions, there was a moderate and significant ($g = -0.70$; $p = 0.014$) reduction in volume during the in-season (55.55 ± 26.60 weekly non-NHE repetitions) compared with off-season (77.42 ± 46.84 weekly non-NHE repetitions).

From responses relating to methods used by practitioners to select training load during non-NHE-based resistance training (Table 6), it was clear to see that the majority of practitioners make their assessment based on movement quality under load (31 total responses), with several practitioners also reporting in the additional information that they prioritise movement quality over load. In addition to movement quality, practitioners frequently opted for load selections based on repetition maximum or predicted repetition maximum (13 responses each) and 20 responders indicated that they make their selections based on rate of perceived exertion (RPE) of Likert scales. 15 responders indicated that loads are selected by the athletes, however as several of the responders that indicated that they use repetition maximum, RPE/Likert scales, and repetition maximum/predicated repetition maximum as well as athlete selected loads, it is possible that athletes select loads within a range of a previously determined maximum and adjust accordingly based on the RPE/Likert scale during a given session.

Methods used to assess athlete training adaptations are reported in Table 7. Thirty practitioners identified that they assess adaptations in eccentric hamstring strength, with 28 stating that they use isometric measures of hamstring strength, with only 12 opting to assess concentric hamstring strength. Other commonly used tests included hamstring flexibility (24 responses) and maximal running velocity (25 responses). Only seven practitioners reported that they assess muscle architectural adaptation.

Given the nature of thematic analyses, the themes identified through the open-ended questions are discussed herein. Practitioners were asked a number of open-ended questions to explore individual perceptions of training for the mitigation of HSI and development of athletic performance. The thematic analysis of these responses is presented herein.

Question: 'What is your current understanding of the modifiable risk factors for hamstring strain injury?'

The majority of practitioners identified that they have an appreciation for the multifactorial nature of HSI risk. As presented in Table 8, the key risk factors identified by practitioners were eccentric hamstring strength, training load and FL. This seems to offer support to the data presented in Table 7, which highlights that the majority of practitioners surveyed conduct regular testing of eccentric hamstring strength and load monitoring. On the other hand, much fewer practitioners conduct regular assessment of FL, which is likely due to a lack of accessibility given the monetary cost of 2-B ultrasound machines and the specialist training required to accurately conduct such assessments. Although seven practitioners identified a lack of facilities as a key limiting factor to their current practice (presented in Table 9), with several practitioners stating that they considered a lack of access to strength testing facilities as a

Table 6. XXXX.

	Profession						
Methods Used	Strength and Conditioning Coach	Sports Therapist	Sports Scientist	Physiotherapist	Athletic Therapist	Sports Rehabilitator	Total
Repetition maximum	5	4	1	3	-	-	13
Predicted repetition maximum	6	4	-	2	-	1	13
Rate of perceived exertion / Likert scale	9	5	3	2	1	-	20
Movement Quality	14	7	2	6	1	1	31
Subjective / guess	4	-	-	2	-	-	6
Trial and error	3	4	1	1	-	1	10
Velocity-based (e.g., accelerometer/linear position transducer)	7	-	1	2	-	1	11
Train to momentary muscle failure	-	2	-	-	1	1	4
Athlete selected	3	8	1	2	-	1	15
Do not determine	-	-	-	1	-	-	1
Repetitions in reserve	3	-	-	-	-	-	3
Percentage of body weight	1	-	-	1	-	-	2

Table 7. XXXX.

Tests Used	Profession: Strength and Conditioning Coach	Sports Therapist	Sports Scientist	Physiotherapist	Athletic Therapist	Sports Rehabilitator	Total
Eccentric hamstring strength	10	8	2	8	-	2	30
Isometric hamstring strength	7	10	-	9	-	2	28
Hamstring muscle architecture	3	1	-	2	-	1	7
Repetition maximum	3	3	1	1	-	2	10
Running technique	4	2	-	3	1	-	10
Kinematic analysis	4	2	-	1	1	2	10
Hamstring flexibility	8	9	1	5	1	-	24
Strength-endurance	4	5	-	3	-	2	14
Maximum running velocity	10	6	2	5	-	2	25
Concentric hamstring strength	1	6	1	3	1	-	12
Running force-based assessment	1	1	-	2	-	2	6
Horizontal force-velocity	2	-	-	-	-	1	3

Table 8. XXXX.

Understanding of HSI risk factors	Frequency of Occurrence	Sample of Practitioner Narratives
Eccentric Strength	17	"Lower levels of eccentric hamstring strength (along with other factors) have been shown to increase risk of injury." "Weak hamstrings measured during the NHE has been shown to contribute to injury risk." "I've had athletes with hamstring pulls before (it was our most common injury in 2020). We did Nordic Hamstring curls 4–5 sets of 5 + reps 3–4 times per week. I think that volume was just too high, especially with their high volumes of sprint and baseball-specific training added on top of it."
Training Load	*15*	*"Load management and fatigue-monitoring are the two biggest factors I know of." "Considering load when combined with objective data Reducing HSI risk factors by exposing players to HSD/>90% max speed" "Monitoring weekly exposures to HIS to identify peaks in acute training volume and adjusting training to manage."*
Fascicle Length	*10*	*"Fascicle length is important. Short and weak = bad news." "Two-week window where fascicle length adaptation will then reduce."*
Flexibility	*6*	*"Reduced flexibility can be a risk for injury"*
Previous HSI	*3*	*"A history of previous HSI can increase risk of future injury, although this can be mitigated to some extent through training"*
Age	*3*	*"Age – we've observed a few more injuries in our older players (>30) than in the younger players in the squad"*
No Knowledge	*3*	*"Minimum to none." "Not heard the term."*
Running Mechanics	*2*	*"Adapted to prevent injury (e.g., knees not going beyond big toe in sprint patterns or jump patterns)."*
Isometric Strength	*1*	*No additional comment provided*
No Predictive Value	*1*	*"No predictive validity or model available to predict injury."*

limiting factor, only one practitioner stated that they considered a lack of access to ultrasound as a limiting factor. Given some of the limitations and criticisms of methods used[15] to estimate bicep femoris long head FL, it is possible that practitioners do not consider lack of ultrasound testing as a limiting factor due to potential measurement error. However, it is also possible that given the evidence that increases in knee flexor strength from eccentric training

Table 9. XXXX.

Compliance Strategy	Frequency of Occurrence	Sample of Practitioner Narratives
Compliance	10	"Some athletes do not like the gym, finding ways to achieve the adaptations can be tricky." "Fear factor of certain stimulus' during a week. (E.g., Sprint Exposure and Eccentric Stimulus)." "Player buy-in. Sprinting and doing a hard exercise."
Multi-Disciplinary Team	*10*	*"Some sports coaches lack appreciation and understanding." "Coach's/players can ramp sessions inappropriately and result in potential overload at inappropriate times." "There are instances where an athlete will have an unplanned team training session. These can vary from 10 competition-based sprints to a 3 mile run and everything in between. These accumulate a much larger workload than anticipated."*
Time with Athletes	*9*	*"Structure of the semi-professional rugby environment, players in full time work with families. Length of training sessions and not impacting on rugby specific training." "My key challenge is working for a part time team, which means there are only 2–4 training hours within the week, which is mainly match specific."*
Facilities	*7*	*"No weights at training so players have to perform SL deadlifts at home with whatever equipment they have available." "Lack of really good quality assessment (e.g., Nordbord)."*
Volume of Match-Play	*7*	*"Game volume; periodisation around the game schedule." "Only work with athletes from Sept-June, they play for teams outside of the school and so there sometimes is an overtraining component, youth athletes who think they are invisible from injury or push return too soon." "Crowded fixture schedule makes ability to prescribe maximal strength sessions difficult."*
Athlete Education	*6*	*"The perceived DOMS and people worrying about this occurring and the ramifications of that." "The ability of the athlete to understand the importance and completing the exercise correctly."*
Staffing Ratio	*5*	*"Player to coach ratio during some sessions can limit the ability to error identify and correct in technique." "Staff to player ratio. Not enough staff to keep track of everything being done properly."*

seem to be associated with increases in FL,[9,10] practitioners may be satisfied that a measured increase in knee flexor strength may likely be associated with increased FL, even if it is not something they have actively measured.

> Question: 'What do you believe to be the most important intervention strategy/strategies to reduce incidence and/or risk of hamstring strain injury?'

Interestingly, 15 practitioners identified training load, including exposures to HSR and the identification of acute peaks in training load as a key HSI risk factor, with 20 practitioners stating that they believe exposure to HSR or match-play specific HSR as a key strategy to mitigate HSI risk (Table 10). As seen in Table 3, 23 surveyed practitioners identified that they collect GPS data for the purposes of monitoring HSR exposures. On the other hand, as seen in Table 9 there is several themes that can be identified relating to the challenges associated with load monitoring and exposure to HSR within practice and within an multi-disciplinary team (MDT). Key themes emerged relating to the difficulties in coordinating load exposure and management within the MDT, for instance coaches and players ramping training sessions which may cause acute spikes in HSR exposure at a time within the training week which may increase the likelihood of an injurious event due to insufficient recovery from previous sessions or insufficient recovery time before the next planned exposure or match day. Additionally, several practitioners identified a lack of communication within the MDT (across support departments and sports coaches), which may lead to an ill-planned training week, or lead to unplanned training exposures, with one participant indicating that unplanned training sessions in their area of work may include anything from 10 competition-based sprints to a three-mile run, both of which could significantly increase total weekly HSR exposure or total running volume.

Exposure to HSR seems to be a clear strategy adopted by practitioners as part of a training strategy with the aim of reducing HSI risk. Given the links between acute spikes in HSR load and the common HSR-based mechanism of HSI,[16–18] it seems imperative that MDTs (including sports coaches) must strive for better communication. Better communication and forward planning seem crucial to appropriately monitor and periodise HSR exposes across training mesocycles, which in-turn would hopefully allow MDTs to be proactive in their ability to adjust planned training exposures in response to the often chaotic reality of sport, particularly at the elite level in which fixture congestion and re-scheduling of fixtures may be commonplace. However, it should be noted that a greater number of training intervention and long-term athlete load monitoring studies are required to further better support this notion.

Table 11

Table 10. XXXX.

Intervention Strategies	Frequency of Occurrence	Sample of Practitioner Narratives
1. Exposure to HSR	16	"Exposure to high-speed running volume and maximal velocity efforts." "Exposure to >90% max speed x2 weekly."
1.1 Match-Day Specific HSR	*4*	*"Regular exposure to matchday HSR Session Distances." "Load exposure equal to game specific ranges."*
2. General Strength Training	*11*	*"I believe a focus on hip dominant hamstring exercises are the most important strategies to reduce hamstring strain incidence due to preferential activation of the Biceps Femoris." "Multiplanar Strengthening."*
2.1 Eccentric Strength Training	*13*	*"Strength based interventions, specifically eccentric in nature."*
2.2 Isometric Strength Training	*4*	*"We also focus on end-range isometrics (PNF style hamstring stretches) and eccentric overload (NHE). I believe these help the hamstring handle the immense stretching/eccentric forces found in sprinting or in sports."*
2.3 Concentric Strength Training	2	*"Combined series of resistance training (isometric, concentric & eccentric."*
3. Managing Exposure / Load Monitoring	*12*	*"Monitoring fatigue through measuring a Countermovement jump, 12 inch drop depth jump RSI or short 10–20 yd sprint prior to training. We don't train at high intensity if they cannot achieve within 5% of their peak, and I think training in a non-fatigued state is crucial for preventing injury." "Not over exposing athletes to match days or training sessions." "Not over exposing athletes to match days or training sessions if their long lever hamstring strength is reduced when compared to the norm or when compared bilaterally."*
4. Technique Modification	5	*"To reduce the risk of HSI there are a number of fundamental technique elements (may be similar across many movements) that could be adapted to prevent injury (e.g., knees not going beyond big toe in sprint patterns or jump patterns)."*
5. Flexibility & Mobility	*4*	*"Developing Hip Joint & Knee Joint Mobility / Flexibility."*
6. Communication & Education	*4*	*"Managing a players risk and exposure through communication with S&C / technical coaching staff." "Education to the players on how to treat them when it comes to DOMS or tightness."*
7. Improving FL	2	*"Eccentric Loading to increase FL."*
8. Recovery	2	*"Work to rest ratio, need an efficient work to build tolerance and enough recovery."*
9. Compliance	*1*	*"NHE most effective, but compliance matters."*
10. Deceleration Ability	*1*	*"Hamstrings with rapid hamstring deceleration/chaos work."*

Better communication and forward planning within the MDT may well reduce incidence of future HSIs, however better athlete education also seems imperative to the long-term success of any strategy to improve training practices. Practitioners cited compliance with training from athlete as well as some aspects of fear of adverse training effects such as DOMS as factors which currently limit their practice. While the likes of DOMS have previously been cited as potential limitations of eccentric resistance training[7] compliance with training interventions has also been found to be key in the success of training for the mitigation of HSI risk.[10]

However, it should be highlighted here that six practitioners stated that they use micro dosing (defined by Cuthbert et al.[19] as '"the division of total volume within a micro-cycle, across frequent, short duration, repeated bouts") within their training practices to minimise the likelihood of athletes missing session components or increase the compliance with training methods (presumably through reducing risk of adverse effects such as DOMS through lower volumes of training spread across a training week or larger mesocycle). Table 12.

Discussion

The aim of this study was to provide a detailed overview of applied practices relating to training for the mitigation of HSI risks in sport. The hypotheses that practitioners would utilise lower volumes of NHE training than suggested by Mjølsnes et al.[8] and that practitioners would utilise a broader range of resistance training methods than just the NHE alone was upheld. Further, the hypothesis that programmed HSR volumes would be higher during the off-season than in-season was supported, whereas the hypothesis that practitioners would consider negative training responses such as DOMS as a barrier to training was rejected.

The results of the thematic analysis indicate three key areas need to be addressed as a result of the current study.

Table 11. XXXX.

Compliance Strategy	Frequency of Occurrence	Sample of Practitioner Narratives
Elsewhere in Training Week	*15*	*"[The session component] is repeated later in the week in the off-season. In season it a modified session may be performed later in the week depending upon the athlete and what our fatigue monitoring is telling us (e.g., are we making them sore too close to a game or not)." "We will typically have a general plan of Nordic hamstring curl volume as well as other exercises' volume that we try to get done each week. So, if an athlete has to forgo an intense session due to fatigue, we will attempt to get the planned session done the next time they are not fatigued." "At some point in the week [the athlete] will catch up even if it is just a couple of sprints."*
Athlete Responsibility	7	*"At our level of rugby union, we do not have the structure to be able to monitor compliance of resistance training sessions. We place a large emphasis outside of the rehabilitation setting on players adhering to strengthening sessions in their own time." "Usually, players are instructed to perform it at home." "Just adapt and encourage players to double up sets on other exercises."*
Yes	*6*	*No additional information provided*
Micro-Dosed	*6*	*"My approach to compliance is to include hamstring maintenance as part of a pre/post session activity based around the athlete's regular gym routine/session." "Include exercises that helps to either hamstring strength, endurance or flexibility into warm up of all training, including sports training, so that missing a session or two will not be an issue."*
Dependant on Fixtures	5	*"Dependant on fixture schedules and when the session was missed may determine if only some of the missed work is completed, i.e., if it's close to match day they may only do part of the session missed, so a reduction in volume is given." "Incorporation into where the fatigue will not effect game related activity/"*
HSR > Resistance Training	*3*	*"If speed target missed eccentric exercise must be completed. If speed attained less concerned at missing resistance exercise." "Typically, if gym session(s) are dropped a greater focus will be spent on high-speed running to mitigate some potential loss of training (i.e., NHE)."*
Athlete Education	2	*"We educate our players that if they do not comply to S&C programmes, their chance of injury increases."*
Missed Opportunity	2	*"If possible, but typically that is just a missed opportunity."*
No – Due to Recovery	*1*	*"I do not catch up on missed sessions as adequate recovery time is needed before the next hamstring session."*
Underpinned by GPS	*1*	*"If possible, but players on live GPS so normally targets met."*

Firstly, practitioners may require better education around the use of micro dosing to improve compliance and reduce potential adverse training effects. Micro dosing of the strength training stimuli is still a relatively new concept within strength and conditioning and injury management, however a recent systematic review and meta-analysis by Cuthbert et al.,[20] offers promising insight into the potential for micro dosing around congested fixture scheduling and indicates a need for more empirical research, to allow practitioners to further develop their understanding and application of the method. However, education could be further improved through the availability of continued professional development workshops or clinics offered by governing bodies. For future generations of S&C and injury practitioners, academics should develop teaching and learning around the use of micro dosing as a regular practice.

The second key finding from the current study is that athletes require better education in relation to the benefits of training practices and methods. This education should also address the potential responses to training, including long-term adaptations and short-term consequences such as DOMS, and whether the presence of DOMS is linked to a decrease in performance levels or an increased likelihood of injury. Additionally, educating the athlete as to the strategies used to implement eccentric training, such as the use of micro dosing to minimise individual session exposures, placement of the eccentric training stimulus in the week (e.g., where loading may be positioned away from match-day HSR exposures or incorporated into a warm-up). However, as DOMS is often attributed to unaccustomed exposures to eccentric loading,[21] a micro dosing approach and / or efforts to ensure a continued compliance to at least some eccentric load across the mesocycle may mitigate some of the likelihood of DOMS in the first place.

While athlete education certainly does not come without its challenges, such as a need to adjust the use of terminology used and buy-in or willingness from the athletes themselves to learn, patient education in a clinical

Table 12. XXXX.

Compliance Strategy	Frequency of Occurrence	Sample of Practitioner Narratives
Athlete Testing / Monitoring	19	More accurate tracking and a wider variety of overall testing of performance (acute and chronic), "Access to technology to provide more objective feedback on training adaptation - drive buy in." "More frequent monitoring of strength and architecture of hamstrings. Too infrequent at the moment - would help with interventions." "HSR currently performed during football session within game training, but we have objective measurement tools available."
Athlete Education	*8*	*"Education to the players, so they understand the reasons why they are doing it, how it's likely to make them feel, and not to worry if they do feel that way." "Access to technology to provide more objective feedback on training adaptation - drive buy in."*
Increased Time with Athletes	*6*	*"More frequency of training and greater volume of strength training."*
Developing an Individualised Approach	*6*	*"I could improve by providing all players with hamstring injury prevention programmes, rather than a select few, who have either suffered previous HSI's or have personally asked for a programme." "Continue to alter sets/reps/range/distance based on individual responses / beliefs to exercise and training."*
Practitioner Education	*5*	*"More understanding of interactions between gym-based training and sprint performance (acute and chronic)." "I'd like to discover methods of training to help prepare athletes for the "chaos" that can happen in their sport. A slight slip, overstretch, etc." "An equivalent hamstrings load metric. It's difficult to add apples (HI load) with oranges (tonnage of lifting). It would be useful to have a metric that it would be inform us that [for instance] 3 x6 × 30 kg of hams curls equals [a similar volume-load] to 45 m of high intensity run."*
Developments in the MDT	*5*	*"More collaboration between S&C staff and myself, gathering and building around both school and outside schedule to take everything into consideration." "Better long-term planning and buy-in from coaches."*
Training Consistency	*4*	*"Trying to have more consistency. But when you have a large period of 2 games a week sometimes recovery is more important." "More frequency of training and greater volume of strength training. More consistent sprint training exposure."*
Recovery Time / Strategies	*2*	*"Being able to give players the optimum amount of rest." "Nutrition advice, as I feel work and rest recovery is best as it can be. Whether nutrition intake could play a role in contributing injuries."*

healthcare setting has been shown to be effective. Additionally, as many athletes start their athletic careers in some form of academy, perhaps an early incorporation of athlete education which is continued throughout the athletic journey may develop a long-term understanding of training interventions. Unfortunately, there is a lack of experimental research in relation to the role of athlete education in the subsequent success of training programmes. There is relatively little research in the field of clinical physiotherapy. Lu et al.[22] that found that the use of a physical training programme combined with the use of educational materials (such as education around the importance of physical exercise in lymphatic health) for the patient reduced the onset lymphedema following breast cancer surgery, compared with just education alone or neither education or physical intervention. While this study offers some support for the importance of patient education in physiotherapy practice, it is limited by the design of the interventions, given that there was no intervention only group without the educational materials. Additionally, the group sizes were highly skewed with $n = 415$ in the no control group, $n = 672$ in the education only group and $n = 130$ in the education plus intervention group. Two additional qualitative studies were conducted firstly by Mudge et al.[23] that considered the perceptions of physiotherapists and whether they are comfortable with a 'person-centred approach', and secondly by Jäppinen et al.[24] that explored physiotherapists perspectives of patient education in total hip arthroplasty. Both studies found that while physiotherapists valued patient education, most felt that their practice was dominated by a biomechanical / biomedical approach to clinical reasoning which limited their capacity to consider the patient at the core of their reasoning.

While the aforementioned studies around patient education in clinical physiotherapy are not directly reflective of strength and conditioning practice they likely provide a key social commentary on the practices and perhaps limitations of the applied practitioner, in that are practitioners too heavily focused on evidence-based interventions, rather than adapting to an evidence informed approach that may better suit the individual athlete in front of them, or at least involving the athlete in their evidence-based thinking?

To the authors' knowledge Weldon et al.[3] conducted the first study that actively considered the perceptions of both coach and athlete in strength and conditioning practice and found that athletes clearly considered strength and conditioning important or very important for the development of volleyball skill. While there is certainly still a need for more research in this area to investigate the benefits of athlete education in relation to the success of training interventions, it seems wise for practitioners to strive to engage athletes with developing their understanding of strength and conditioning practice if it is something they clearly view as important. Developing athlete understanding from some of the basic principles of training at youth level through to some of the more complex rationales such as micro dosing and placement of the training stimuli as athletes get older, will hopefully help to improve training compliance and therefore reduce some of the modifiable risk factors for injury.

A key observation from the study is the consistent volume of NHEs programmed during both the off-season and in-season. Ripley et al.[10] found that eccentric hamstring training is superior for HSI risk reduction, especially with compliance rates above 50.1% and intervals of less than three weeks between sessions. Practitioners generally incorporate eccentric training year-round, ensuring missed sessions are made up, which is crucial for reducing HSI risk.

Regular eccentric training is important as Timmins et al.[25] showed that benefits from eccentric hamstring training can revert to baseline after two weeks without the stimulus. However, compliance and HSI risk might improve if NHE volumes were reduced. Current averages (12.7 ± 12.3 in-season and 17.3 ± 12.2 off-season) exceed the minimum required for adaptation, as Cuthbert et al.[9] found eight weekly repetitions sufficient for significant improvements in FL. Further research is needed to confirm if lower NHE volumes can still enhance maximal strength and FL without initial high-volume phases.

Most practitioners also use NHEs alongside other resistance training and HSR. The study noted no significant difference in non-NHE resistance training volumes between seasons, except for a moderate reduction in upper-end volumes during the in-season due to competition periodisation. RDL and glute bridge/hip thrust variations are commonly used exercises. These exercises potentially enhance bicep femoris long head adaptations due to their combined knee flexion and hip extension, important for HSR.

However, there is a lack of studies examining the effects of combined training methods, like combining NHEs with other resistance training or HSR, on HSI risk mitigation. Further research is needed to investigate these combined approaches and their efficacy.

Conclusion

The results of this study indicate that practitioners use diverse methods, HSR, NHE, and other resistance training methods with the aim of reducing HSI risk across both in-season and off-season periods, with off-season training characterised by higher volumes and an emphasis on technical such as front-side mechanics. Varying approaches to defining HSR and sprint thresholds are adopted by practitioners, where some use absolute values (HSR: 5.50–6.00 m·s?^{1}, sprinting: 7.50–8.00 m·s?^{1}) and others apply relative thresholds (HSR: 50–75% max velocity, sprinting: $\geq 85\%$ maximum velocity), potentially affecting training effectiveness through under loading or not meeting required intensities. Despite the broad application of HSR, there is a need for better monitoring and integration of HSR into tactical sessions, especially given the resource demands of GPS technology. Future research is required to enhance ecological validity through the investigation of combined HSR and resistance training which utilises more than single-exercise interventions. To bridge the gap between researchers and practitioners, studies should look to establish minimum effective doses in applied setting with currently used practises such as micro-dosing for better athlete adaptation monitoring and training quantification in elite sports settings.

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Statements and declarations

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Supplemental material

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