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The role of strength alterations and gender in collegiate athletes' risk of developing hamstring strain injury: a prospective study

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The role of strength alterations and gender in collegiate athletes' risk of developing hamstring strain injury: a prospective study

by

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Dedication

This report is dedicated to my grandmother, Jeanet Strohhofer, and my mother, Sandra Pryor. Gama, I owe all of this to you. It is thanks to you that so many doors in life have been opened for me; I hope that what I've done with the opportunities afforded me by your actions and support have made you proud. Mom, thanks for always having my back and being just a phone call away, even at three o'clock in the morning. These past two years have been fraught with ups-and-downs, but you both have weathered every proverbial storm with me; thank you for standing by me, both in fair winds and in foul seas.

It is also dedicated to the memory of my grandfather, Anton Strohhofer. Gada, I hope that I have made you proud.

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Last, but certainly not least, I wish to thank one of the most influential mentor figures in my life, Dr. Rachel Cowan. Rachel, were it not for the things I learned from you during my time at the Miami Project, I would not be where I am today. Your wisdom, support, and advice have been my saving grace on many an occasion. Thank you for believing in me.

Abstract

The role of strength alterations and gender in collegiate athletes' risk of developing hamstring strain injury: a prospective study

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Hamstring strain injury (HSI) is among the most prevalent sports-related injuries observed in athletic populations, particularly in sports involving high-speed movements. Although previous history of HSI is generally accepted as a risk factor for development of subsequent HSI, there is less consensus regarding the relative risk for HSI posed by other variables. Very little of the existing body of research on HSI risk factors is prospective in nature, and virtually none has examined the effect of gender on HSI. This prospective study aimed to address two of the more significant gaps in the current research on HSI by investigating the potential role of strength imbalances present at the beginning of the competitive season in the relative risk of HSI development; furthermore, this study sought to elucidate what effect, if any, that athlete gender has on the variables measured. In addition to study findings, this report discusses considerations for future research, particularly with respect to study design and methodology, and identifies potential areas warranting further investigation.

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Chapter I: Introduction

Hamstring strain injury (HSI) is generally accepted to be one of the most prevalent injuries across a wide range of sports, including (but not limited to) rugby, sprinting (track and field), American, Australian,[3,14] and Gaelic[11] football, and soccer.[1,4] They are the "most prevalent muscle injury in sports involving rapid acceleration and maximum speed running,"[9] and account for a substantial proportion of injuries sustained among competitive athletes. The majority of hamstring injuries appear to occur during high-speed exercise, such as sprinting;[8,12] in particular, it has been suggested that such injuries typically occur during the terminal swing phase of gait.[15] Injury severity varies, and can range from mild to severe, the latter of which occasionally necessitates medical intervention.

There is a general consensus amongst many researchers that, despite receiving a great deal of attention in the literature, hamstring injury rates have not declined in recent years. In studies which have examined potential risk factors in HSI, the principal clinical risk factor for injury recurrence is the existence of a past hamstring injury,[2,5,7,10,14] although some studies have not replicated this finding.[3] A wide assortment of other factors, such as age, strength imbalances, flexibility, and fatigue, have all been posited as potential risk factors for development of HSI, but in all cases, their role as risk factors remains inconclusive.

In addition to the negative impact of HSI both from a medical and a competitive standpoint, there is a growing body of research suggesting that the deleterious effects of HSI may persist even after injured athletes have undergone rehabilitation programs and successfully returned to training and competition. Most notably, some studies have suggested long-term, persistent changes in muscle structure occur after HSI. Atrophy of injured hamstring muscles with concurrent hypertrophy of the uninjured hamstring muscles has been observed, typically with concomitant scarring.[13]

A common theme in the literature[6] is the need for prospective studies that allow for the determination of both preventative and rehabilitative strategies for hamstring strain injury; however, to date, the majority of studies conducted have been retrospective in nature. Furthermore, an examination of the existing body of research on HSI reveals that the participants recruited have been almost overwhelmingly male, with very few studies including both male and female subjects; the potential role that gender may play in the development of HSI, then, is an area that has yet to be fully explored.

This study attempted to address two of the more significant gaps in the current research on hamstring strain injury: the need for research that is prospective in design, and the dearth of research on HSI in female athletes. The purpose of this study was to determine if between-limb strength imbalances present at the outset of the competitive season are associated with an increased relative risk of developing HSI as the season progresses, and if previous history of HSI contributes to an increased relative risk, versus that of hamstring-uninjured controls. In addition, this study investigated the role of gender in HSI by evaluating both male and female athletes.

Chapter II: Materials and Methods

PARTICIPANTS

Nine male and five female (males 19.9 ± 1.8 years, females 20.2 ± 1.3 years) NCAA Division I athletes competing for the University of Texas at Austin's track-and-field team participated in this study. Recruitment of subjects was conducted across all track-and-field subdisciplines, with participating athletes competing in throws, javelin, high jump, horizontal jump, and mid- and long-distance running events. Athletes both with and without history of lower limb injury, including history of previous hamstring strain injury, were recruited for participation; however, in order to ensure participant safety, athletes unable to train or compete as a result of injury at the time of initial testing were subsequently excluded from the study.

Participants were asked to place their knees on the padded portion of the NordBord device (qutbluebox, Queensland, AUS) and assume a kneeling position with their arms crossed over their chest. A photograph demonstrating the proper starting position for the test is shown in Figure 1. This photograph was also included in the informed consent document for this study. Once positioned properly on the NordBord, participants' ankles were secured to the device via padded ankle supports attached to load cells. Data collected during testing was transmitted via a wireless receiver to a laptop computer running HS Logger software included with the NordBord device.

Figure 1: The Proper Starting Position for the NH Exercise Using the Nordbord Device.

EXPERIMENTAL PROTOCOL

Participants attended two experimental sessions, which coincided with the approximate beginning and end of the track-and-field competitive season, respectively. Each experimental session lasted approximately thirty minutes to one hour. After an informed consent document approved by the University of Texas at Austin's Institutional Review Board was reviewed and signed by individuals who wished to participate, subject demographics and injury history information were collected. Participants were also asked to state which limb they considered to be their "dominant" limb. Photographs demonstrating the proper performance of the Nordic hamstring (NH) exercise used during the tests were then provided to participants, allowing them to familiarize themselves both with the movement that would be performed during testing, as well as with the NordBord testing device. In addition to these photographs, participants were given verbal directions regarding the proper execution of the NH exercise: beginning from the start position, participants were instructed to lower themselves towards the ground in a slow, controlled manner, using their hamstring muscles to resist gravity. Upon reaching a point at which they became unable to do so, they were instructed to allow themselves to fall gently forward and catch themselves with their hands.

Prior to data collection with the NordBord during the first test session, information on participant demographics and injury history was collected. In order to become familiarized with the NH exercise movement and the NordBord device itself, participants were given the opportunity to conduct a practice NH exercise before the start of testing. Six successive trials of the NH exercise using the NordBord device were completed at each test session. Neither the familiarization nor the experimental trials were timed; participants completed the NH exercise trials at a self-selected, comfortable pace.

During the second test session, participants were asked if any injuries had occurred since the first test session prior to the start of data collection. In the absence of injury, participants who wished to take part in the second testing session did so. In the case of athletes who did not wish to participate in a second test session due to soreness experienced after the first test session, researchers performed a verbal follow-up, using the participant's answers to the initial demographics and injury history report administered during the first test session as a basis of comparison for answers given during the second test session.

Participants were instructed to contact the principal investigator in the case of injury occurring between the first and second test sessions. Injured athletes were provided with a Schedule 1 form for the collection of additional data regarding the nature and severity of the injury, as well as the areas affected and what, if any, diagnostic methods were used to confirm injury nature.

DATA ANALYSIS

Load cells attached to the ankle supports collected force data across all six NH exercise trials, using a 10-millisecond sampling period. HS Logger software algorithms determined the maximum force production value (Newtons) of the right and left limbs. These max force production values were subsequently used in determining percent imbalance between limbs and the directional bias of this imbalance. Negative percent imbalance values indicated a strength bias in favor of the left limb; positive percent imbalance values indicated a strength bias in favor of the right limb. The limb (right or left) achieving the higher relative maximum force was considered to be the physiologically dominant or "preferred" limb. The dominant limb as determined by testing was compared with the participant's self-reported dominant limb.

Track-and-field sub-disciplines represented in the study were further categorized as throwing (throws, javelin), jumping (high jump, horizontal jump, hurdles), or running (mid- and long-distance events) prior to statistical analysis, in order to assess what role, if any, that an athlete's sub-discipline may have on strength imbalances.

STATISTICAL ANALYSES

Mean ± SD was calculated for male and female participant age, height, weight, and number of years of sport participation.

Unpaired t-tests with Welch's correction were used to compare maximum dominant limb force and maximum non-dominant limb force in males and females. Further unpaired t-tests with Welch's correction compared between-limb (dominant limb versus non-dominant limb) percent force imbalance in males and females. Data is reported as mean ± SD. Paired t-tests were used to compare maximum force produced between each participant's dominant and non-dominant limbs.

Binary logistic regression analyses were performed to examine which factors could best predict hamstring injury history. The outcome variables were defined as HSI at any point in the athlete's career history and HSI in the past year. Factors used as predictors in the equation were participant gender (male versus female), preferred limb (PL) maximum force, non-preferred limb (NL) maximum force, asymmetry ratio (between PL and NL) and the percent difference in maximum force production. Asymmetry ratio was calculated as NL maximum force/PL maximum force, where 1 equals perfect symmetry. Percent difference in maximum force production was defined as (PL-NL)/(PL+NL)*100%.

One-way ANOVA with post-hoc Tukey's Multiple Comparison Test was used to determine if differences in dominant-limb max force exist between throwing, jumping, and running event subcategories. Additional one-way ANOVA with post-hoc Tukey's Multiple Comparison Test was used to investigate differences in between-limb percent force imbalance across the aforementioned event subcategories. Data is reported as mean ± SEM.

An alpha level $p \leq 0.05$ was accepted as the threshold for statistical significance for these tests.

Chapter III: Results

Male and female participants' age, height, weight, and years of track-and-field experience are listed in Table 1.

Gender	Age	Years' experience	Height (cm)	Weight (kg)
Male	19.9 ± 1.8	5 ± 2.9	182.0 ± 10.1	87.0 ± 27.1
Female	20.2 ± 1.3	6.3 ± 2.9	172.2 ± 6.1	57.6 ± 3.0

Table 1: Participant Demographics. Data is presented as *M* ± *SD*.

MAXIMUM DOMINANT-LIMB FORCE

Male athletes produced a significantly higher max dominant-limb force than female athletes (413.1 ± 37.3N and 219.5 ± 31.82N, respectively; $p < 0.005$), as well as a significantly higher max non-dominant limb force (378.5 ± 31.78N and 201.1 ± 28.59N, respectively; $p < 0.005$.) These results are shown in Figures 2 and 3, respectively. Furthermore, a significant difference was found between the maximum force produced by participants' preferred and non-preferred limb (346.8 ± 35.2N and 318.8 ± 31.7N, respectively; $p = 0.001$.) Results are shown in Figure 4. No difference was found in between-limb percent force imbalance in male versus female athletes.

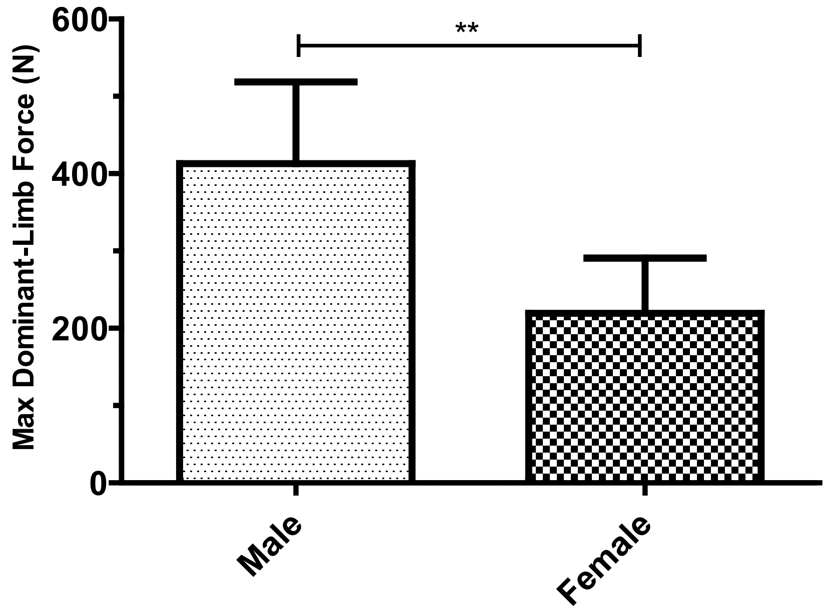

Figure 2: Maximum Dominant-Limb Force (Newtons) Exerted at Any Point During the Test Session ($M \pm SD$; $^{**}p < .005$).

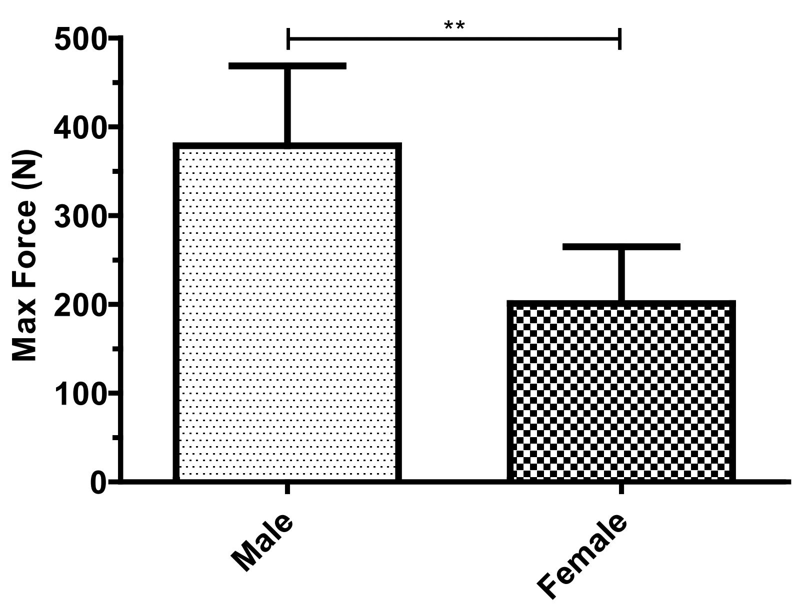

Figure 3: Maximum Nondominant Limb Force (Newtons) Exerted at Any Point During the Test Session ($M \pm SD$; $^{**}p < .005$).

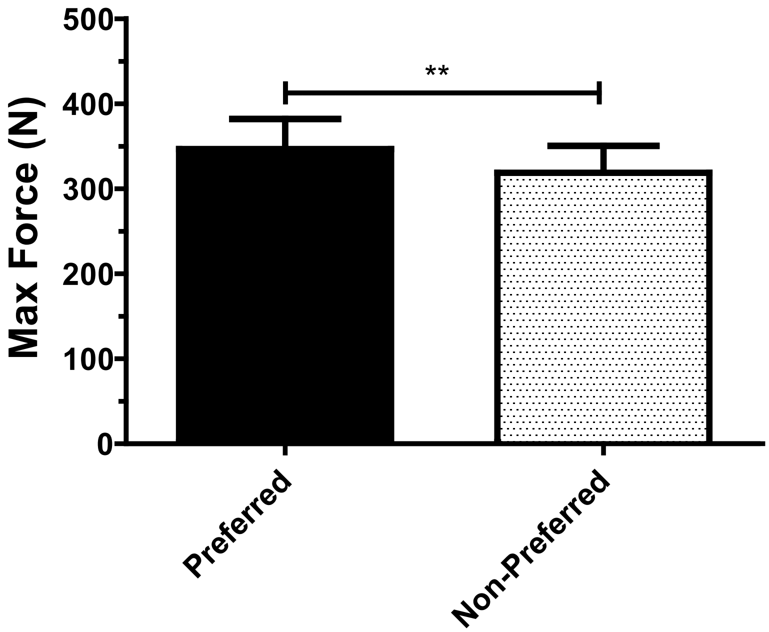

Figure 4: Maximum Force Produced in Preferred Versus Non-preferred Limb (*M* ± *SD*; **p = .001).

A significant difference between maximum dominant-limb force among the three track-and-field event subcategories was found ($p < 0.02$.) Post-hoc tests revealed that throwing and running ($p < 0.05$), and throwing and jumping ($p < 0.05$) differed significantly. However, there was no difference in between-limb percent force imbalance among these event subcategories.

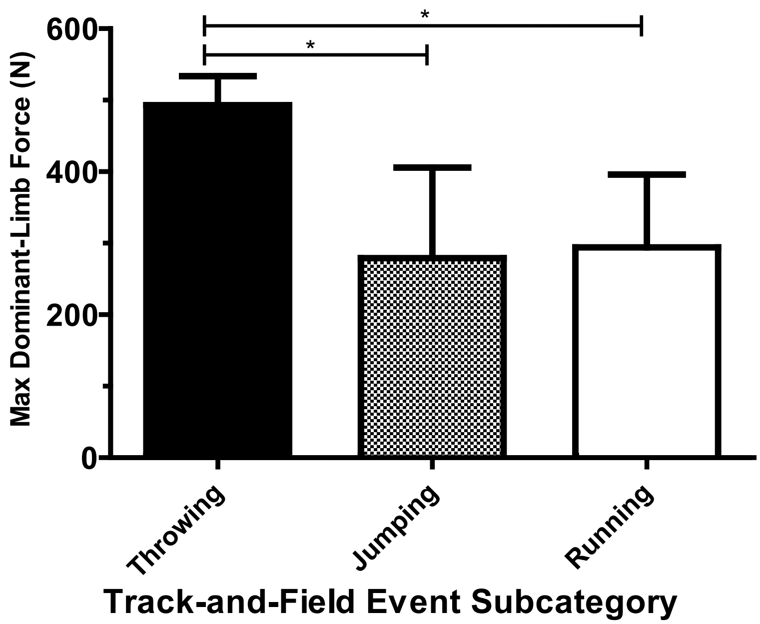

Figure 5: Maximum Dominant-Limb Force (Newtons) for Track-and-Field Events Categorized as Throwing-, Jumping-, or Running-Based Subdisciplines. (*M* ± *SD*; **p* < .05).

Predictors of Career HSI

Two binary logistic regression models were used to determine factors that could serve as potential predictors of HSI history occurring at any point in the athlete's history. Covariates used in Model 1 were gender, maximum PL force, maximum NL force, and asymmetry ratio. None of these 4 factors were found to be significant predictors of career HSI history (p > .05.) Covariates used in Model 2 were gender, maximum PL force, maximum NL force, and percent difference in PL and ML maximum force. None of these 4 factors were found to be significant predictors of career HSI history (p > .05.)

Predictors of Past-Year HSI

Models 1 and 2 were again used to determine which factors would best predict HSI history within the past year. The same covariates were used in each model as were used in the analysis of career HSI history. Neither the 4 factors used in Model 1 ($p > .05$) or Model 2 ($p > .05$) were found to be significant predictors of past-year HSI history. In interpreting the results of the binary logistic regression analyses, the low number of subjects recruited for this study should be noted.

Chapter IV: Discussion

In this study, male athletes across all track-and-field event subcategories produced a significantly higher maximum dominant-limb force as well as a significantly higher maximum non-dominant limb force during the NH exercise trials than did female athletes. This finding in and of itself is not necessarily surprising, as gender differences in strength are generally well-established in the literature; however, from a training and prevention standpoint, it may warrant further investigation, particularly with regards to ensuring that rehabilitation protocols for hamstring strain injuries in athletes take into account gender differences in strength, and do not adopt a "one-size-fits-all" that may be insufficient or fail to address underlying strength deficits or imbalances; similarly, the finding that preferred-limb maximum force production was significantly higher than non-preferred limb force production may also be of note.

One of the more unanticipated findings of this study was that athletes participating in track-and-field events falling under the throwing subcategory generated significantly higher maximum dominant-limb forces than did athletes in the jumping and running subcategories. Future studies may wish to investigate if there is a gender effect in this respect as well, as the current study's sample size did not allow for such analysis. Although no significant differences in between-limb percent force imbalances between the different event subcategories, or between males and females, were found in this study, investigation in future research utilizing larger sample sizes may be warranted. Interestingly, it was observed that in some instances athletes' self-reported dominant limb was not their physiologically dominant limb (i.e., that the limb the athlete believed to be his or her dominant limb achieved a lower maximum force during the NH exercise testing than did the contralateral limb.) Such trends were observed in athletes both with and without history of HSI. While this study did not establish a correlation between reported versus actual dominant limb and relative risk of HSI, future research in this matter may be warranted in order to better determine what role, if any, such findings may play in the risk of HSI development.

It was not found that gender, preferred-limb maximum force, non-preferred limb maximum force, and either asymmetry ratio or percent difference in maximum force production between PL and NL served as predictors of either career HSI history or past-year HSI history; however, there are various possible explanations for these findings. Sample size is once again a limiting factor; although this study failed to establish these factors as viable predictors of HSI history, this should not discourage future research utilizing larger sample sizes from re-examining their predictive value. Furthermore, although all individuals participating in this study were track-and-field athletes, there was nevertheless substantial heterogeneity exhibited among them with respect to nature and severity of past lower-limb injuries, racial and ethnic background, and the nature of the track-and-field event in which they competed. Future research may wish to examine the impact that lower-limb injury type, track-and-field event, and athlete race/ethnicity may have on the predictive value of the factors assessed in this study.

LIMITATIONS AND CONSIDERATIONS FOR FUTURE RESEARCH

There are several limitations to this study that warrant consideration, particularly with regards to their implications for future studies on hamstring strain injury in collegiate athletes utilizing a prospective design. The most obvious of these is the relatively small sample size used in this study, which complicates the process of drawing definitive conclusions from the data. Additionally, as only track-and-field athletes were tested, these results may not be applicable to other athletic disciplines.

This study was designed to begin and end concomitantly with the athletes' competitive season. While this allows researchers to collect prospective data over the course of a competitive season in order to more definitively evaluate relationships between potential risk factors for HSI present at the beginning of the season and the associated relative risk of HSI development throughout the season, the impact of athlete willingness to participate in a study of this nature should not be underestimated. Although there were no reports of injuries sustained by the study participants, participant retention from the first to the second test session was nevertheless exceptionally poor, with only one participant out of the original fourteen tested willing to participate in the second test session; poor participant retention, therefore, is the second major limitation of this study.

In attempting to discern the underlying reasons for poor participant retention, it was found that many of the athletes complained of some soreness and discomfort persisting for a day or two after the first test session. While this would likely still present a challenge to participant recruitment and retention during the offseason, it is perhaps more so during the competitive season. Although testing dates were scheduled such that they were as temporally far-removed from competitions as was possible, in the present study, athletes who chose to refrain from participating in the second test session nonetheless still consistently cited concerns about soreness during competition as their reason for withdrawing from the study. It may be advisable that future prospective research conducted during the competitive season gives special consideration to potential conflicts that may arise due to interplay between season length, frequency and intensity of training and competition, and the physiological and temporal demands resulting from research participation over the course of the season.

References

1. Askling C, Karlsson J, Thorstensson A. Hamstring injury occurrence in elite soccer players after preseason strength training with eccentric overload. *Scand J Med Sci Sports*. 2003;13:244–250.

2. Bennell K, Wajswelner H, Lew P, et al. Isokinetic strength testing does not predict hamstring injury in Australian Rules footballers. *Br J Sports Med*. 1998;32:309–314.

3. Cameron M, Adams R, Maher C. Motor control and strength as predictors of hamstring injury in elite players of Australian football. *Phys Ther Sport*. 2004;4:159–166.

4. Clanton TO, Coupe KJ. Hamstring strains in athletes: diagnosis and treatment. *J Am Acad Orthop Surg*. 1998;6:237–248.

5. Croisier JL. Factors associated with recurrent hamstring injuries. *Sports Med*. 2004;34(10):681–695.

6. Drezner JA. Practical management: hamstring muscle injuries. *Clin J Sport Med*. 2003; 13:48–52.

7. Gabbe BJ, Bennell KL, Finch CF, Wajswelner H, Orchard JW. Predictors of hamstring injury at the elite level of Australian football. *Scand J Med Sci Sports*. 2006;16: 7–13.

8. Garrett WE, Califf JC, Bassett FH: Histochemical correlates of hamstring injuries. *Am J Sports Med*. 1984;12:98–103.

9. Hoskins W, Pollard H. The management of hamstring injury—part 1: issues in diagnosis. *Manual Ther*. 2005;10(2):96–107.

10. Orchard J. Intrinsic and extrinsic risk factors for muscle strains in Australian football. *Am J Sports Med*. 2001;29(3):300–303.

11. O'Sullivan K, O'Ceallaigh B, O'Connell K, Shafat A. The relationship between previous hamstring injury and the concentric isokinetic knee muscle strength of Irish Gaelic footballers. *BMC Musculoskelet Disord*. 2008;9(30).

12. Sherry MA, Best TM. A comparison of 2 rehabilitation programs in the treatment of acute hamstring strains. *J Orthop Sport Phys*. 2004;34(3):116–125.

13. Silder A, Heiderscheit BC, Thelen DG. MR observations of long-term musculotendon remodeling following a hamstring strain injury. *Skeletal Radiol*. 2008;37:1101–1109.

14. Verrall GM, Slavotinek JP, Barnes PG, Fon GT, Spriggins AJ. Clinical risk factors for hamstring muscle strain injury: a prospective study with correlation of injury by magnetic resonance imaging. *Br J Sports Med*. 2001;35(6):435–439.

15. Worrell, TW. Factors associated with hamstring injuries an approach to treatment and preventative measures. *Sports Med*. 1994;17(5): 338–345.