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Preseason Hamstring Muscle Weakness Associated with Hamstring Muscle Injury in Australian Footballers*

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ABSTRACT

Hamstring muscle strain is the most prevalent injury in Australian Rules Football, accounting for 16% of playing time missed as a result of injury. Thirty-seven professional footballers from an Australian Football League team had preseason measurements of hamstring and quadriceps muscle concentric peak torque at 60, 180, and 300 deg/sec measured on a Cybex 340 dynamometer. Players were studied prospectively throughout the 1995 season. During that time, six players sustained clinically diagnosed hamstring muscle injuries that caused them to miss match-playing time. The injured hamstring muscles were all weaker than in the opposite leg in absolute values and hamstring-to-quadriceps muscle ratios. According to our *t*-test results, hamstring muscle injury was significantly associated with a low hamstring-to-quadriceps muscle peak torque ratio at 60 deg/sec on the injured side and a low hamstring muscle side-to-side peak torque ratio at 60 deg/sec. Flexibility (as measured by the sit-and-reach test) did not correlate with injury. Discriminant-function analysis using the two significant ratio variables resulted in a canonical correlation with injury of 0.4594 and correctly classified legs into injury groups with 77.4% success. These results indicate that preseason isokinetic testing of professional Australian Rules footballers can identify players at risk of developing hamstring muscle strains.

Hamstring muscle strain is a common injury in sports that involve sprinting. It is particularly prevalent in Australian Rules Football, resulting in 16% of playing time missed through injury.[15] Australian Rules Football is the predominant football code in the southern states of Australia. There are 21 players per side (18 on the playing field with 3 interchange players). The playing field is a large oval with approximate dimensions of 165 × 140 meters. The ball is also oval, made of leather, resembling a rugby football. Playing time is divided into 4 quarters that last 27 minutes each on average, during which play is almost continuous. There is no offside rule, and the ball is progressed forward by punt kicking, handballing (i.e., holding the ball in the palm of one hand and striking it with the fist of the other hand), and running with the ball, which must be bounced every 10 meters.

Causative factors for hamstring muscle strains have been studied for many years,[2] with muscle weakness and lack of flexibility the most commonly postulated intrinsic risk factors. Fatigue and inadequate warmup,[21] poor lumbar posture,[7] use of thermal pants,[18] and previous injury have also been suggested (34% of hamstring muscle strains in professional Australian Rules Football are recurrences[15]), but there is a paucity of conclusive prospective studies of risk factors.[12] Factors that may explain the relatively high rate of hamstring muscle strain among Australian Rules Football players include repetitive punt kicking and repeated sprinting efforts over the 2-hour game.

Some circumstantial data have suggested a link between preparticipation hamstring muscle weakness and subsequent injury. Burkett[2] reported on 6 footballers from a group of 37 who, on the basis of preseason testing, were determined by the authors to be at high risk of hamstring muscle injury in one limb because of muscle weakness. Four of these six players (66.7%) subsequently developed hamstring muscle strains, all in the predicted

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limbs. However, prospective results were not published for the control group. Heiser and coworkers[6] published a study in which the rate of hamstring muscle injuries in a college football team decreased after a protocol was introduced to correct preseason strength deficits. The reduction of injuries was impressive, but the intervention was not randomized, and, consequently, confounding variables may have influenced the results. Individual strength results of players who sustained injuries were also not reported.

In this prospective study, we attempted to identify preseason predictors of hamstring muscle strain, particularly isokinetic strength variables, in a sport with a high rate of this injury.

MATERIALS AND METHODS

Subjects

A total of 37 professional football players from the senior list of an Australian Football League team were included in the study. The senior list (players eligible for senior grade matches) included 41 players, all of whom were required to undergo preseason fitness testing as part of their professional contracts. Two players were unavailable for testing before the start of the season, and two players who sustained long-term injuries (one fractured tibia and one ACL tear) in the preseason period were excluded from the study group because they would miss most of the season's matches. The average age of the 37 subjects was 22.0 ± 4.1 years, average height was 185.3 ± 6.5 cm, and average weight was 85.6 ± 9.1 kg. With respect to kicking, 11 players were left-leg dominant and 26 players were right-leg dominant.

Preseason Measurements

Preseason fitness measurements were conducted on all players at the Sports Science Department of the New South Wales Academy of Sport, Sydney, Australia, in February 1995. This protocol consisted of routine sets of tests performed regularly on players. Most of the players tested in the 1995 preseason had undergone such testing previously. Test results for four players, who were unable to undergo testing during February because of an injury other than a hamstring muscle strain, were from the same tests performed earlier in the preseason (November); otherwise, all players were tested within a 2-week period.

The tests were performed to assess quadriceps and hamstring muscle function, aerobic and anaerobic fitness, running speed, lower body explosive strength, body composition, flexibility, and abdominal strength.

Quadriceps and hamstring muscle function were assessed in an upright, seated position using a Cybex 340 System concentric isokinetic dynamometer (Chattecx Corp., Chattanooga, Tennessee) at angular velocities of 60, 180, and 300 deg/sec. Subjects were positioned as recommended in the Cybex 340 users' manual. The protocol consisted of four practice trials before three recorded trials with a 30-second recovery period between tests at the different speeds. Subjects alternated between starting with their left and right legs and were given consistent verbal encouragement for all trials. Gravity correction was used. Peak torque relative to body weight (in newton-meters per kilogram), side-to-side comparisons, and hamstring-to-quadriceps muscle ratios were determined and recorded.

Flexibility of the low-back and hamstring muscles was assessed using the sit-and-reach test.[19] Aerobic fitness was assessed by having subjects run 12 kph on a treadmill with the incline increasing 1% per minute while on-line analysis of oxygen intake was performed. The test was terminated at volitional fatigue. We calculated $\dot{V}O_2max$ values relative to body weight (in milliliters per kilogram per minute). Anaerobic fitness was assessed on an air-resistant cycle Repco EX10 ergometer (Repco, Melbourne, Australia). Each subject did 5 maximal 6-second efforts every 30 seconds. Total work (in joules per kilogram), peak power (in watts per kilogram), work and power decrements (percentages), and blood lactate (millimolar) 2 minutes after exercise were determined and recorded.[4] Lower body explosive strength was assessed with a countermovement jump and a three-step running jump using a Vertisonic sonar device (Lafayette Instrument Company, Lafayette, Indiana) to measure jump height. Acceleration and speed characteristics were evaluated from a standing start using timing lights at 10, 20, 30, and 40 meters. Peak velocity was calculated as the average velocity between 30 and 40 meters. Abdominal strength was measured using a Seven-stage test.[4] Body composition was assessed by measuring skin-fold thickness at eight sites.[4]

Players were informed of the results of preseason tests, although no specific rehabilitation program was given to those players with strength deficits. History of hamstring muscle injury was noted from the player's medical file (no question was specifically asked of the player). The past-injury history was somewhat limited, because less detail was known about players who had started their careers at other clubs.

Injury Definition

Players were studied prospectively throughout the 1995 season by the senior author (JO), who was blinded to the preseason-testing results, and who, as club doctor, attended all matches and training sessions. There were 22 matches in the season (an average of one match per week). Players were required to perform static stretches of the major muscle groups (including hamstring) before and after every training session and match.

A hamstring muscle injury was diagnosed clinically and included in the study if it caused the player to miss match-playing time. The severity of the injury must have resulted in the player leaving the field during a match or being unavailable to play an official match. Minor injuries, where only practice time was missed or where a player was able to continue in a match, were excluded. The standard history (during a match or training) was a sudden onset of hamstring muscle pain occurring during sprinting or kicking. Clinical signs were local tenderness, pain and reduced range on the straight-leg raise test on the affected side, and pain and reduced strength on resisted knee flexion while prone.

Statistical Analysis

Preseason test results were statistically analyzed with respect to injury occurrence. Most variables were analyzed by comparison of mean values with respect to injured versus noninjured players. Because hamstring muscle injuries occurred on a particular side of the body, analysis for hamstring and quadriceps muscle strength variables was performed on injured versus noninjured legs. The combination variables of the ratio of hamstring muscle-to-quadriceps muscle and the ratio of hamstring muscle strength between both sides of the body were included. Results for the noninjured leg in an injured subject were included in the control group for hamstring-to-quadriceps but not for hamstring-to-opposite hamstring. For some variables, there were missing data because a player was unable to complete the full battery of tests due to a minor injury affecting one area of the body.

Comparison of mean values between injured and noninjured groups were calculated using two-tailed *t*-tests. For almost all of the variables tested, Levene's test for Equality of Variances did not suggest unequal variances, so *t*-tests were calculated assuming equality of variances between groups. Discriminant-function analysis (a statistical technique that highlights the variables most important in the identification of groups) was then used to determine which strength parameters were best able to predict injured and noninjured hamstring muscles. The data were analyzed using the SPSS computer software program (SPSS Inc., Chicago, Illinois).

RESULTS

Six players sustained clinically diagnosed hamstring muscle injuries that caused them to miss playing time. Three players missed playing time in one match, one missed two matches, one missed four matches, and one missed six matches (an average of 2.5 matches missed, with matches 1 week apart). All injuries were unilateral, and the injured hamstring muscles were all weaker than the opposite leg in absolute values and hamstring-to-quadriceps muscle ratios. Three left legs and three right legs were injured. Three were in the players' dominant kicking legs, and three were in the nondominant legs. For the entire study group, peak torque values for hamstring and quadriceps muscle strength were not significantly different between the dominant and nondominant legs, so further analysis was performed without regard for leg dominance.

Mean values ±SD for the hamstring and quadriceps muscle strength variables in the injured versus noninjured limbs are listed in Table 1. The injured limbs had significantly lower hamstring-to-quadriceps muscle ratios at 60 deg/sec, hamstring-to-opposite hamstring muscle ratios at 60 deg/sec, and hamstring muscle peak torque at 60 deg/sec.

Measured factors that did not significantly correlate with injury included age, height, weight, preferred kicking leg, level of abdominal strength, body composition, sit-and-reach test results, $\dot{V}O_2max$ results, history of hamstring muscle injury, and the various measures of anaerobic fitness. The results other than isokinetic strength measures, which showed a trend toward association with injury (without achieving statistical significance), were a higher score on countermovement jump ($t_{35} = -1.38$, $P = 0.177$), lower abdominal strength ($t_{35} = 1.52$, $P = 0.137$), higher thigh skin-fold thickness ($t_{35} = -1.50$, $P = 0.143$), higher peak velocity ($t_{27} = -1.22$, $P = 0.235$), and lower $\dot{V}O_2max$ ($t_{33} = 1.33$, $P = 0.192$).

Sit-and-reach test values correlated poorly with subsequent injury, with five of the six injured players being close to the group mean (±10 cm) for this test. Neither flexibility nor strength measures significantly correlated with history of past injury.

Discriminant-function analysis was performed using the variables of lower hamstring-to-quadriceps muscle ratios at 60 deg/sec and hamstring-to-opposite hamstring muscle ratios at 60 deg/sec to classify limbs into injured versus noninjured groups. The noninjured limbs in the six

TABLE 1
Comparison of Hamstring and Quadriceps Peak Torque of Injured and Uninjured Legs (mean ± SD)

Variable[a]	Injured legs ($N = 6$)	Uninjured legs	*t* value	df	*P* value
H_{60} (N-m/kg_{bw})	1.75 ± 0.27	2.08 ± 0.31	2.61	69	0.011[b]
H_{180} (N-m/kg_{bw})	1.60 ± 0.12	1.75 ± 0.27	1.28	69	0.205
H_{300} (N-m/kg_{bw})	1.09 ± 0.16	1.27 ± 0.25	1.74	70	0.087
Q_{60} (N-m/kg_{bw})	3.19 ± 0.42	3.14 ± 0.33	−0.32	70	0.751
Q_{180} (N-m/kg_{bw})	2.52 ± 0.27	2.52 ± 0.28	0.01	70	0.993
Q_{300} (N-m/kg_{bw})	1.85 ± 0.21	1.88 ± 0.26	0.30	70	0.764
H_{60}:Q_{60}	0.550 ± 0.065	0.662 ± 0.071	3.69	69	0.000[b]
H_{180}:Q_{180}	0.626 ± 0.063	0.695 ± 0.087	1.74	69	0.087
H_{300}:Q_{300}	0.592 ± 0.096	0.680 ± 0.123	1.71	70	0.092
H_{60}:opp H_{60}	0.880 ± 0.072	1.005 ± 0.103	2.89	60	0.005[b]
H_{180}:opp H_{180}	0.962 ± 0.116	1.007 ± 0.116	0.80	61	0.425
H_{300}:opp H_{300}	0.939 ± 0.135	1.018 ± 0.154	1.10	62	0.275

[a] H, hamstring muscle (60, 180, 360 deg/sec); Q, quadriceps muscle; H:Q, hamstring-to-quadriceps muscle ratio (60, 180, 300 deg/sec); H:opp H, hamstring-to-opposite hamstring muscle ratio (60, 180, 300 deg/sec); N-m/Kg_{bw}, newton-meters per kilogram of body weight.
[b] Significantly different at $P < 0.05$.

TABLE 2
Classification of Legs According to Canonical Discriminant-Function Analysis

Variable	Predicted injured	Predicted uninjured	Total
Actual injured	5	1	6
Actual uninjured	13	43	56
Total	18	44	62

injured subjects were not included in the analysis because the ratio of hamstring-to-opposite hamstring muscle at 60 deg/sec was not independent of the values for the injured group. Six legs had missing values and were also excluded from the analysis, leaving 62 limbs for classification. A canonical discriminant function was established with coefficients of 0.735 for hamstring-to-quadriceps muscle ratios at 60 deg/sec and 0.479 for hamstring-to-opposite hamstring muscle ratios at 60 deg/sec. This canonical discriminant function had a correlation of 0.4594 with injury ($P = 0.0009$). Limbs were classified according to this function (Table 2). This analysis yielded a sensitivity of 83.3%, a specificity of 76.8%, and a positive predictive value of 27.8% with 48 limbs (77.4%) correctly grouped.

The lowest quartile values for the two ratio measures were 0.607 for hamstring-to-quadriceps muscles and 0.920 for hamstring-to-opposite hamstring muscles, both at 60 deg/sec. Four of the injured limbs were in the lowest quartile for both of these measures, and the other two were in the lowest quartile for one of each.

DISCUSSION

This study shows a significant association between preseason hamstring muscle weakness and subsequent development of hamstring muscle strain injury. The best predictors were the ratios of hamstring-to-quadriceps muscles and hamstring-to-opposite hamstring muscles, both at 60 deg/sec. Despite the moderate sample size, a good discriminant-function model was established to predict injury on the basis of these peak torque ratios. Hamstring muscle injuries were common in our study team, but no more so than other teams in Australian Football League competition.

The study also suggests that measuring peak torques at 60 deg/sec rather than at higher speeds provides greater yield in terms of injury prediction for this group. This observation supports the protocol of Heiser and coworkers,[6] who used H_{60}:Q_{60} ratios less than 0.60 to prescribe a hamstring muscle-strengthening program for college footballers. Previous studies have been inconclusive with respect to the best speed for testing, with Jönhagen and associates[10] suggesting slower speeds and others suggesting speeds of 180 deg/sec or faster.[11,16] The hamstring-to-quadriceps muscle ratio has been shown to be less at 60 deg/sec than at faster speeds,[8] and slower speeds may more accurately show ratio deficits, despite not being close to the physiologic speeds of sprinting.

Based on the current research and the recommendations of Heiser et al.,[6] preseason concentric isokinetic testing of footballers provides valuable information. Players are at substantially increased risk of hamstring muscle strain when they have hamstring-to-quadriceps muscle ratios (60 deg/sec) of less than 0.61 or hamstring-to-opposite hamstring muscle ratios (60 deg/sec) of less than 0.92 on either limb. These players should undertake a hamstring muscle strengthening program and be periodically retested to confirm the success of intervention.

Because eccentric muscle-strength testing is now available, its role in predicting injury should be further evaluated. Tests of eccentric strength performed in the supine rather than seated position may better represent physiologic conditions[16,17] but should be separately evaluated, because peak torques and ratios vary under these circumstances.[9] A more functional ratio of eccentric hamstring-to-concentric quadriceps muscle strength has recently been suggested.[1] Eccentric testing involves fewer natural movements and is more difficult to perform, which may pose compliance problems if used as a routine screening measure.

The role of past injury in reducing hamstring muscle strength must be further evaluated. Jönhagen and coworkers[10] have shown a decrease in strength (in particular, eccentric strength) after hamstring muscle injury, but other studies have reported normal strength after injury.[13,22]

Some studies have retrospectively shown a decrease in hamstring muscle flexibility after an injury.[10,22] Others have failed to show such a correlation,[5,7] perhaps because of inadequate methods. Knapik and coworkers[11] showed that strength and flexibility imbalances were prospectively associated with lower extremity injuries in general, but not specifically with the muscle group where the imbalance was found. Cowan and coworkers[3] found that subjects in both the least flexible and most flexible quintiles on a sit-and-reach test were more likely than those in the middle quintiles to get injured, suggesting that both hypo- and hypermobility may be intrinsic risk factors for injury.

The sit-and-reach test was used in this study as a composite measure of flexibility. Although this is a nonspecific test that does not differentiate between limbs, the poor correlation with injury suggests that strength deficits are more relevant to the development of hamstring muscle injury than abnormal flexibility in this group. Being elite professional footballers, the subjects may have been more motivated to stretch and would have greater muscle strength overall than the general population. The popliteal-angle test may be a superior way to measure range of hamstring muscle movement. Because hamstring muscle injuries apparently occur with the muscle well within the limits of range of motion, a test of muscle stiffness or compliance at midrange may be a superior way to measure flexibility than range of motion tests.[20]

Hamstring muscle strain was diagnosed on clinical grounds and included in the study if playing time was missed. The cause of hamstring muscle pain in Australian footballers is often unclear. In some, if not most, cases a classic muscle strain is the cause, but other diagnoses often appear to overlap, including referred pain from the lumbar spine, the gluteal and piriformis muscles, and the sciatic nerve. Different risk factors may apply to different diagnoses, and magnetic resonance imaging is likely to be helpful in future research.[14]

Professional sports teams are very useful for studies of this type. Recruitment of subjects is easy, and the players undertake a standardized program that includes the same number and type of training sessions. A limitation is that coaches and players have a much stronger incentive to prevent imminent injury than to contribute to the scientific literature. In the year of the study, players were given the results of all their tests, but no emphasis was made regarding relative hamstring muscle weakness (by comparison, those players with high skin-fold thickness [body fat] were strongly encouraged to reduce this factor). We believe that, in the context of the current study, it is unlikely that players would have placed much significance on their Cybex dynamometer strength-test results, or that this knowledge would have affected their predispositions to injury. However, because of our results, our team now has strong evidence that hamstring muscle weakness is a risk factor for injury. Therefore, we have a responsibility to emphasize the importance of correcting strength imbalances to players, which would likely affect results if the same group were studied in the future.

Further study should prospectively evaluate the predictive value of superior measures of flexibility, eccentric isokinetic testing, and the relationship of past hamstring muscle injury with current deficits. Another area of recommended research would be to evaluate the best method of reversing strength deficits.

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