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A Comparison of 2 Rehabilitation Programs in the Treatment of Acute Hamstring Strains

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Study Design: Prospective randomized comparison of 2 rehabilitation programs.

Objectives: The objectives of this study were to compare the effectiveness of 2 rehabilitation programs for acute hamstring strain by evaluating time needed to return to sports and reinjury rate during the first 2 weeks and the first year after return to sport. A third objective was to investigate the relationship between functional testing performance and time to return to sports and reinjury rates after return to sport.

Background: Hamstring muscle strains are common in sports and often result in chronic pain, recurrent hamstring strains, and reduced sports performance. Current rehabilitation programs are primarily developed anecdotally and lack support from prospective, randomized research.

Methods and Measures: Twenty-four athletes with an acute hamstring strain were randomly assigned to 1 of 2 rehabilitation groups. Eleven athletes were assigned to a protocol consisting of static stretching, isolated progressive hamstring resistance exercise, and icing (STST group). Thirteen athletes were assigned to a program consisting of progressive agility and trunk stabilization exercises and icing (PATS group). The number of days for full return to sports, injury recurrence within the first 2 weeks, injury recurrence within the first year of returning to sports, and lower-extremity functional evaluations were collected for all subjects and compared between groups.

Results: The average (±SD) time required to return to sports for athletes in the STST group was 37.4 ± 27.6 days, while the average time for athletes in the PATS group was 22.2 ± 8.3 days. This difference was not statistically significant ($P = .2455$). In the first 2 weeks after return to sports, reinjury rate was significantly greater ($P = .00343$, Fisher's exact test) in the STST group, where 6 of 11 athletes (54.5%) suffered a recurrent hamstring strain after completing the stretching and strengthening program, as compared to none of the 13 athletes (0%) in the PATS group. After 1 year of return to sports, reinjury rate was significantly greater ($P = .0059$, Fisher's exact test) in the STST group. Seven of 10 athletes (70%) who completed the hamstring stretching and strengthening program, as compared to only 1 of the 13 athletes (7.7%) who completed the progressive agility and trunk stabilization program, suffered a recurrent hamstring strain during that 1-year period.

Conclusions: A rehabilitation program consisting of progressive agility and trunk stabilization exercises is more effective than a program emphasizing isolated hamstring stretching and strengthening in promoting return to sports and preventing injury recurrence in athletes suffering an acute hamstring strain. Future randomized clinical trials should investigate the potential for progressive agility and trunk stabilization programs in the prevention of hamstring strain injury during sports. *J Orthop Sports Phys Ther 2004;34:116-125.*

Key Words: *agility, injury recurrence, muscle injury, physical therapy, stretching*

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Hamstring strains in sprinters and athletes who perform high-speed skilled movements are common injuries and pose complicated rehabilitation challenges, especially when returning athletes quickly and safely to sports participation.[1,4,5,8,13,18,22] A 4-year study[3] of injury rates for the Memphis State University football team showed that hamstring strains were the third most common orthopaedic problem after knee and ankle injuries. Hamstring injuries often result in significant recovery time, along with a lengthy period of increased susceptibility for recurrent injury.[10,20,22] The highest risk for injury recurrence appears to be within the first 2 weeks of return to sports.[20] A study that analyzed 858 hamstring strains in Australian Footballers showed that the rate of recurrence was 12.6% during the first week of return to sports and 8.1% during the second week. The cumulative risk of reinjury for the entire 22-week season was 30.6%.[20] Another study reported that 15 out of 30 sprinters who suffered hamstring strains had previously strained their hamstring.[13]

There is a lack of clinical research regarding the effectiveness of various rehabilitation programs for acute hamstring strains. Not surprisingly, a lack of consensus also exists in the content of these rehabilitation programs. Worrell[26] proposed a rehabilitation program based on the tissue's theoretical healing response. The 4-phase program theorized that progressive stretching and strengthening of the injured tissue would help to remodel and align collagen fibers in the scar tissue.[26] The acute phase (2-4 days) consisted of control of inflammation and early motion of the lower extremity in the sagittal plane. The subacute period consisted of stationary biking, isolated hamstring progressive-resistance exercises, and pain-free stretching. The remodeling phase consisted of continued, isolated, hamstring progressive-resistance exercises (PREs), with the addition of eccentric exercise and continued hamstring stretching. The functional phase included jogging, sprinting, sport-specific drills, and continued hamstring strengthening and stretching.[26] Other authors have described similar programs.[1,5,17] Because the pelvis is the origin attachment site for the hamstring muscles, it has been suggested that neuromuscular control of the lumbopelvic region, including anterior and posterior pelvic tilt, is needed to create optimal function of the hamstrings in sprinting and high-speed skilled movement. Changes in pelvic position could lead to changes in length-tension relationships or force-velocity relationships. This has led some clinicians to utilize various trunk stabilization and progressive agility exercises for hamstring rehabilitation programs.[2,14,25] Trunk stabilization and neuromuscular control exercises have also been shown to be effective in promoting return to sports in athletes with chronic hip adductor pain.[12]

To date, most prospective research on hamstring strains has focused on preventative measures and treatment of chronic hamstring strains.[2,7,9,13,16,21,22] To our knowledge, there are no prospective, randomized studies in the literature investigating the effectiveness of different rehabilitation programs for the treatment of acute hamstring strain. The main objectives of this study were to compare the effectiveness of 2 rehabilitation programs for acute hamstring strain by evaluating (1) time needed to return to sports and (2) reinjury rate during the first 2 weeks and the first year after return to sport. A third objective was to investigate the relationship between functional testing performance and time needed to return to sports and to determine if these tests could guide return to sport after an acute hamstring strain.

METHODS

Subjects

Subjects were recruited using posters and contact with local physicians, athletic trainers, and physical therapists. Twenty-eight subjects were enrolled and 4 did not complete the rehabilitation phase of the study. One subject was involved in a motor vehicle accident and could not continue the exercise program. Two subjects sustained minor injuries, unrelated to their rehabilitation program, which limited their ability to complete the rehabilitation program at the minimum rate of at least 70%. One individual did not follow up for his scheduled appointment or return a phone call. His status is unknown. Of these 4 subjects excluded due to noncompliance, 3 were in the progressive agility and trunk stabilization (PATS) group and 1 was in the hamstring stretching and strengthening (STST) group. All subjects were participating in sport activities (Table 1).

A 4-block fixed-allocation randomization process was used to assign subjects to 1 of 2 intervention groups (Table 2). This process allowed stratification for age and sex, eliminating any potential bias these 2 variables may present. The fact that 4 subjects did not complete the study disrupted our ability to have exactly the same number of males and females within

TABLE 1. Sport activities performed by individuals in the stretching and strengthening (STST) group and the progressive agility and trunk stabilization (PATS) group.

STST		PATS	
Subject #	**Sports**	**Subject #**	**Sports**
1	Baseball, football	1	Football, track (sprinter)
2	Football, track (sprinter)	2	Running, tennis
3	Football, basketball, soccer, track (sprinter)	3	Track (sprinter/jumper)
4	Softball, ultimate Frisbee, racquetball	4	Soccer
5	Softball, basketball	5	Track (sprinter)
6	Softball	6	Softball
7	Triathlon training	7	Soccer
8	Tennis	8	Soccer
9	Baseball, football, hockey	9	Track (sprinter/jumper)
10	Baseball, football	10	Soccer
11	Cross-country, basketball	11	Softball
		12	Baseball, basketball
		13	Track (sprinter)

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TABLE 2. Subject demographics for the individuals in the stretching and strengthening (STST) group and the progressive agility and trunk stabilization (PATS) group.

	STST	PATS
Mean age ± SD (y)	24.3 ± 12.4	23.2 ± 11.1
Age range (y)	14-49	15-49
Males (n)	9	9
Females (n)	2	4
Males, age 14-30 y (n)	8	8
Females, age 14-30 y (n)	1	2
Males, age 31-50 y (n)	1	1
Females, age 31-50 y (n)	1	2

each group. The injuries were classified as first- or second-degree strains based on Craig's[6] original description (Table 3). But this classification system has some subjectivity and there is a lack of research correlating injury grade and time for recovery from injury; therefore, it was not used in the randomization process.

Eleven subjects were randomly assigned to the STST group (Table 4), while 13 subjects were randomly assigned to the PATS group (Table 5). In the STST group, 7 subjects had a first-degree hamstring injury and 4 subjects had a second-degree injury. In the PATS group, 5 subjects had a first-degree injury and 8 subjects had a second-degree injury. Subjects were considered to have a hamstring strain if they had a mechanism of injury likely leading to strain injury of the hamstring muscles (Table 6), tenderness to palpation within the muscle-tendon unit of the hamstring, pain with resisted prone knee flexion, pain with passive tension testing using a passive straight leg raise test, and a limitation of daily or sport activity. Acute injury was defined as an initial injury that occurred within the past 10 days.

Exclusion criteria included nonacute hamstring injuries, a subject not being at least 14 years of age or less than 50 years of age, current other lower-extremity injuries, complete muscle disruption, avulsion injuries, clinical findings suggesting inguinal or femoral hernia, radiculopathy, history of malignant disease, incomplete healing and rehabilitation of pelvis or lower-extremity fractures, coexisting pelvis or lower-extremity fractures, clinical findings showing nerve entrapment, any other impairment limiting participation in the rehabilitation program, or lack of daily compliance (less than 70%) with a home exercise program.

One potential subject was excluded because he had sustained a full-thickness tear of the semimembranosus and semitendinosus at the proximal muscle tendon junction, confirmed by magnetic resonance imaging. Another potential subject was excluded because the physical exam demonstrated posterior thigh pain that was not consistent with a hamstring strain. Two subjects who inquired about the study were excluded because they did not meet the age criterion (14-49 years of age). Seven subjects were excluded because their hamstring injury occurred more than 10 days prior to contacting us. Ten subjects that contacted us via the Internet excluded themselves upon learning that they would need to be evaluated and supervised at our clinic. All of these subjects lived in other states.

FIGURE 1. Hamstring stretch with slow side-to-side rotation, with rotation primarily occurring at the hips as the chest rotates from being over the left leg to being over the right leg.

Subjects agreed not to take nonsteroidal anti-inflammatory medication or receive any other form of treatment during the study. The study protocol was approved by The Committee for Human Subjects at the University of Wisconsin at Madison. Each subject signed an informed consent form and the rights of each subject were protected throughout the course of the study. If a subject was less than 18 years of age, a legal guardian also signed a statement of informed consent.

Procedure

All potential subjects underwent a 30-minute initial history and physical examination session by the lead author to determine if they met the inclusion criteria. Subjects were then randomly assigned to 1 of 2 intervention groups. Of note, 1 subject in the PATS group had had a previous hamstring injury on the contralateral leg, whereas 2 subjects in the STST group had had a previous hamstring injury on the contralateral leg. There were no subjects in either group with a previous hamstring strain on the same leg.

TABLE 3. Muscle Injury Classification System.[6]

Grade	Pathophysiology	Signs and Symptoms
First degree	Represents a tearing of only a few muscle or tendon fibers	Minor swelling and discomfort with no or minimal loss of strength
Second degree	Represents a more severe partial tear without complete disruption of the musculotendinous unit	Clear loss of strength with more discomfort
Third degree	A complete rupture of the musculotendinous unit	A total lack of muscle function and commonly with massive hematomas

TABLE 4. Rehabilitation program for the individuals in the stretching and strengthening (STST) group.

Phase 1
• 10 min of low-intensity stationary biking with no resistence, primarily focusing on continous movement with minimal force required
• Supine hip flexion with knee extension stretch 4 × 20 sec (Figure 1)
• Standing hip flexion with knee extension stretch with slow side-to-side rotation during the stretch, 4 × 20 sec
• Contract-relax hamstring stretch in standing with foot on stool, 4 sets of 10-sec contraction and 20-sec stretch
• Submaximal isometric hamstring sets, 10 reps for 10 sec held at 20° knee flexion and 60° knee flexion while lying supine
• Ice in long-sitting position for 20 min
Phase 2*
• 15 min of moderate-intensity stationary biking, moderate level of resistence and moderate work level; should feel some perceived exertion
• 5 min of moderate-velocity walk
• Supine hip flexion with knee extension stretch 4 × 20 sec
• Standing hip flexion with knee extension stretch with slow side to side rotation, 4 × 20 sec
• Prone leg curls, 3 × 10 reps with ankle weights for resistance
• Hip extension in standing with knee straight using Thera-Band resistance, 3 × 10 reps
• Non–weight-bearing ''foot catches,'' 3 × 30 sec (Figure 2)
• Symptom-free practice without high-speed maneuvers
• Ice for 20 min if any symptoms of local fatigue or discomfort are present

*Progression criteria: Subjects progressed from exercises in phase 1 to exercises in phase 2 when they could walk with a normal gait pattern and do a high knee march in place without pain.

The average time from date of injury to date of program initiation was 3.4 days (range, 1-10 days) for the PATS group and 4.1 days (range, 2-10 days) for the STST group. Each group had 2 treatment phases. In the first phase of treatment for each group, ice was applied to the posterior thigh for 20 minutes after completing the daily rehabilitation sessions. Subjects progressed from exercises in phase 1 to exercises in phase 2 when they could walk with the same stride length and stance time on the injured and uninjured leg, and do a high knee march in place without pain. The STST group (11 subjects) performed static stretching, isolated progressive resistance exercise, and icing. Exercises in phase 1 focused on static stretching and isometric strengthening of the hamstrings (Table 4). In phase 2, dynamic stretching was incorporated with concentric and eccentric hamstring strengthening (Table 4). This program was developed through exercises suggested in various review articles.[1,5,17] The PATS group (13 subjects) performed a rehabilitation program consisting of progressive agility and trunk stabilization exercises and icing. For the purposes of this paper, ''trunk stabilization'' refers to muscular activity of the trunk and pelvis to maintain the spine and pelvis in a desired neutral posture or alignment. The progressive agility exercises begin with movements primarily in the frontal and transverse plane (Table 5). In phase 2, subjects progressed to performing movements in the transverse and sagittal plane (Table 5).

Both rehabilitation programs were completed as a daily home exercise program. Subjects were asked to independently track their exercise compliance by recording days they performed the complete prescribed rehabilitation program on a log and to report their compliance at each follow-up visit. If subjects performed their exercises on less than 7 of the past 10 days, they were not included in the study. To promote honesty, subjects would be allowed continued guidance in their rehabilitation. The 4 subjects who were excluded from the study because of noncompliance had outside influences that prevented them from doing their exercises (such as motor vehicle accident). All subjects were highly motivated to return to sports and were eager to perform the rehabilitation. A minimum compliance of 70% was required and statistical analysis of compliance over 70% was not carried out.

TABLE 5. Rehabilitation program for individuals in the progressive agility and trunk stabilization (PATS) group.

Phase 1

- Low- to moderate-intensity sidestepping, 3 × 1 min
- Low- to moderate-intensity grapevine stepping (lateral stepping with the trail leg going over the lead leg and then under the lead leg), both directions, 3 × 1 min
- Low- to moderate-intensity steps forward and backward over a tape line while moving sideways, 2 × 1 min
- Single-leg stand progressing from eyes open to eyes closed, 4 × 20 sec
- Prone abdominal body bridge (performed by using abdominal and hip muscles to hold the body in a face-down straight-plank position with the elbows and feet as the only point of contact), 4 × 20 sec
- Supine extension bridge (performed by using abdominal and hip muscles to hold the body in a supine hook lying position with the head, upper back, arms, and feet as the points of contact), 4 × 20 sec
- Side bridge, 4 × 20 sec on each side (Figure 3)
- Ice in long sitting for 20 min

Phase 2*

- Moderate- to high-intensity sidestepping, 3 × 1 min
- Moderate- to high-intensity grapevine stepping, 3 × 1 min
- Moderate- to high-intensity steps forward and backward while moving sideways, 2 × 1 min
- Single-leg stand windmill touches, 4 × 20 sec of repetitive alternate hand touches (Figure 4)
- Push-up stabilization with trunk rotation (performed by starting at the top of a full push-up, then maintain this position with 1 hand while rotating the chest toward the side of the hand that is being lifted to point toward the ceiling, pause and return to the starting position), 2 × 15 reps on each side
- Fast feet in place (performed by jogging in place with increasing velocity, picking the foot only a few inches off the ground), 4 × 20 sec
- Proprioceptive neuromuscular facilitation trunk pull-downs with Thera-Band, 2 × 15 to the right and left
- Symptom-free practice without high-speed maneuvers
- Ice for 20 min if any symptoms of local fatigue or discomfort are present

Key: Low intensity, a velocity of movement that is less than or near that of normal walking; moderate intensity, a velocity of movement greater than normal walking but not as great as sport; high intensity, a velocity of movement similar to sport activity.
*Progression criteria: subjects progressed from exercises in phase 1 to exercises in phase 2 when they could walk with a normal gait pattern and do a high knee march in place without pain.

Follow-up visits were scheduled according to patient progress and report of symptoms, which was monitored by phone calls or electronic mail every few days. Subjects had a clinic visit to monitor exercise technique and to re-evaluate their status at least every 7 days. The lead author supervised the rehabilitation programs for both groups. Subjects were allowed to return to sports when they demonstrated 5/5 strength when manually resisting knee flexion in prone with the hip in neutral extension, had no palpable tenderness along the posterior thigh, and when they demonstrated subjective readiness after completing agility and running tests.

On the day of return to sports, a functional testing profile was also performed. The functional tests were administered by the lead author and included a hop-for-height test, hop-for-distance test, 4-hop crossover test, and a 40-yard sprint. The hop tests allowed for comparison between the injured and uninjured limbs. The 40-yard sprint was not comparable between limbs, but because sprinting is the most frequent mechanism of injury, we felt it provided a good indicator of readiness for sports. If subjects reported posterior thigh "tightness" or "twinges" during their running tests, they were not allowed to return to sports. Subjects were encouraged to continue their rehabilitation program at least 3 days per week for 2 months after returning to sports.

Subjects were asked to contact the principal investigator if they sustained a reinjury. Subjects that did not contact the principal investigator within 2 weeks after return to sports were called to inquire about injury recurrence. Due to subject schedules, the timing of these completed calls fluctuated between 14 and 16 days. Subjects were also contacted after 1 year of their return to sport date. A reinjury within the first year after return to sport from the initial injury did include the first 2 weeks of return to sport. A subject was considered to have a reinjury if there was a specific mechanism of injury that caused a return of posterior thigh pain, pain with resisted knee flexion, tenderness to palpation along the muscle-tendon unit, and decreased ability to do sport activities (perceived strength and power).

There were a total of 8 reinjuries for both groups. Four of these reinjuries were evaluated in the clinic by the primary investigator. Three other athletes were initially seen as high school seniors and, at the time of their reinjury, were attending college and therefore unable to return to the clinic. The other subject chose not to return to the clinic because of personal reasons. The 4 subjects that were not physically evaluated did undergo a phone interview and confirmed a specific mechanism of injury, unilateral posterior thigh pain similar to the location of the initial injury, pain lasting longer than 2 days (subjects

TABLE 6. Mechanism of injury responsible for causing hamstring strains in the athletes participating in this research study.

Mechanism of Injury	n
Sprinting	13
Acceleration (transitioning to a full sprint from a relatively stationary position)	5
Lunging for tennis ball or first base	2
Plant and kick in soccer	2
Slip and fall	1
Stretching	1

TABLE 7. Incidence of reinjury for the individuals in the stretching and strengthening (STST) group and progressive agility and trunk stabilization (PATS) group.

	Reinjury Rate	
Group	**2 wk**	**1 y**
STST (n = 11)	6 (54.5%)	7 (70.0%)
PATS (n = 13)	0 (0%)	1 (7.7%)

TABLE 8. Time required for return to sports for the individuals in the stretching and strengthening (STST) group and the progressive agility and trunk stabilization (PATS) group.

Group	Injury to Return to Sports	Start of Rehabilitation to Return to Sports
STST	37.4 d (SD, 27.6; SE, 8.3; range, 10-95 d)	33.3 d (SD, 25.9; SE, 7.8; range, 8-88 d)
PATS	22.2 d (SD, 8.3; SE, 2.3; range, 10-35 d)	18.8 d (SD, 9.4; SE, 2.6; range, 5-33 d)

were asked whether the pain was only unilateral and had lasted longer than 2 days to prevent confusion with delayed-onset muscle soreness), and pain with resisted knee flexion.

Data Analysis

All analyses were conducted using SAS statistical software (SAS Institute, Inc., Cary, NC). A Wilcoxon rank sum test was used for statistical analysis of time to return to sport, days of rehabilitation, and functional testing. Fisher's exact test was used to assess reinjury rates between the 2 groups. Injury severity was analyzed with Fisher's exact test and a Wilcoxon rank sum test. A *P* value of .05 was considered significant for all cases.

RESULTS

Sprinting was the most common mechanism of injury (Table 6). This is consistent with previous research documenting the mechanism of hamstring strain.[19,21]

Six of 11 athletes (54.5%) who completed the STST program and none of the 13 athletes (0%) in the PATS group suffered a recurrent hamstring strain within the first 16 days of returning to sports. Seven of 10 athletes (70%) who completed the STST program and 1 of the 13 athletes (7.7%) in the PATS group suffered a recurrent hamstring strain within the first year of returning to sports after their initial hamstring strain (Table 7). One athlete from the STST program died in an unfortunate accident unrelated to this study and was unable to complete the 1-year follow-up. The likelihood of reinjury was significantly less for the athletes in the PATS group at 2 weeks after returning to sports (*P* = .00343, Fisher's exact test) and at 1 year after returning to sports (*P* = .0059, Fisher's exact test).

Time needed to return to sports showed no significant difference (*P* = .2455, Wilcoxon rank sum test) between the 2 groups (Table 8). Average time required to return to sports from date of injury for athletes in the STST group was 37.4 days (SD, 27.6; SE, 8.3; range, 10-95 days), while the average for athletes in the PATS group was 22.2 days (SD, 8.3; SE, 2.3; range, 10-35 days). The difference for time to return to sports was also compared between the athletes who suffered reinjury within 2 weeks of return to sport (6 subjects) and those who did not suffer reinjury (18 subjects). The average time required to return to sports for the 6 athletes who were subsequently reinjured was 35.2 days (SD, 26.7 days), while the average for athletes who were not reinjured was 25.4 days (SD, 19.5 days). This difference was not significant (*P* = .789, Wilcoxon rank sum test).

The number of days of rehabilitation was also analyzed. The athletes in the STST group had an average of 33.3 days (SD, 26.0; SE, 7.8; range, 8-88 days). The athletes in the PATS group had an average of 18.8 days (SD, 9.4; SE, 2.6; range, 5-33 days). This

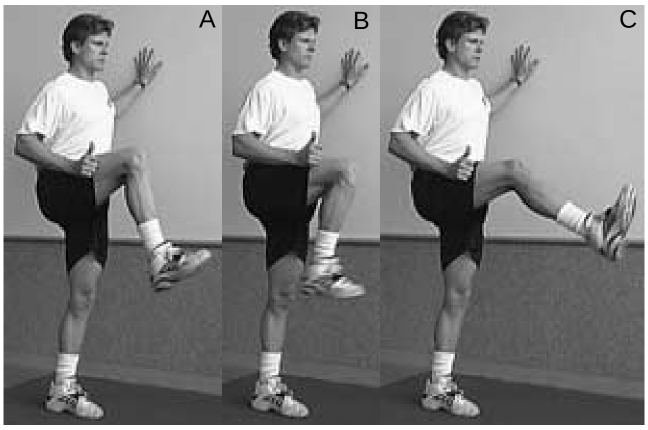

FIGURE 2. Foot catch exercise. This exercise was described and pictured in a review article by Worrell[26]; "The athlete stands parallel to a wall, using the upper extremity on the wall side as needed for stability, and simulates the swing phase of walking or running. During the swing phase, the athlete performs a quick quadriceps contraction and then attempts to catch or stop the lower leg before reaching full knee extension by a hamstring contraction."

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difference in rehabilitation days was not statistically significant (P = .2461, Wilcoxon rank sum test).

In the STST group, 7 of 11 (64%) athletes had initially suffered a first-degree strain, while the other 4 (36%) had suffered a second-degree strain. In the PATS group, 5 of 13 athletes (38%) suffered a first-degree strain, while the other 8 athletes (72%) suffered a second-degree strain. Analysis of injury severity showed no statistical significance between the STST and PATS groups (P = .219, Chi-square test), (P = .414, Fisher's exact test), and (P = .2421, Wilcoxon rank sum test).

Performance on the functional testing profile was also compared between the 2 rehabilitation groups (Table 9) and between the reinjured subjects and the subjects without reinjury (Table 10). The comparison included absolute values between the involved and uninvolved lower extremities of the 2 groups, as well as individual percent differences of involved and uninvolved sides compared between groups. There was no significant difference ($P<.05$) with these comparisons.

DISCUSSION

The major finding in this study was that the rate of reinjury was significantly higher in an age- and gender-matched group of athletes performing hamstring stretching and strengthening exercises, as compared to a group performing progressive agility and trunk stabilization exercises, at 2 weeks and 1 year after return to sport. The progressive agility and trunk stabilization program used in this study requires neuromuscular control, while limiting end range tension on the hamstring muscles. An animal study of muscle laceration suggested that scar weakness is the limiting factor until 10 days postinjury. Thereafter, muscle atrophy is the most important factor in injury recurrence.[15] Orchard and Best[20] suggest early loading of the muscle-tendon unit to avoid secondary atrophy, and simultaneously being careful to avoid overstressing the scar tissue. The progressive agility and trunk stabilization program used in this study controls the early range of motion for dynamic activities by controlling the direction of movement. Frontal plane movements will not increase the length of the hamstring muscle-tendon unit as much as sagittal plane movements. This potentially allows early loading of the injured tissue and return of quick movements without overstressing the healing tissue. The early loading on the hamstring muscles at a protected muscle-tendon length may help to reduce muscle atrophy. The controlled direction of movement permits early retraining of quick changes in agonist and antagonist muscle

TABLE 9. Statistical analysis of functional testing between individuals in the stretching and strengthening (STST) group and the progressive agility and trunk stabilization (PATS) group. P values based on Wilcoxon's rank sum test. Hop tests are measured in cm and sprinting tests are measured in seconds.

Group	Test	Mean	SD	Minimum	Maximum	*P* Value
STST	Hop for height, uninvolved	37.0	11.5	20.3	55.9	.7276
PATS	Hop for height, uninvolved	38.0	9.2	19.1	52.1	
STST	Hop for height, involved	35.6	11.9	17.8	58.4	.4165
PATS	Hop for height, involved	39.0	7.9	25.4	49.5	
STST	Hop for height, involved to uninvolved (%)	96.1	13.5	83.3	131.8	.0637
PATS	Hop for height, involved to uninvolved (%)	104.9	16.4	77.8	134.5	
STST	Hop for distance, uninvolved	160.8	43.6	71.1	215.9	.5239
PATS	Hop for distance, uninvolved	169.2	31.0	111.8	205.7	
STST	Hop for distance, involved	159.7	45.5	71.1	238.8	.5238
PATS	Hop for distance, involved	166.8	29.3	114.3	205.7	
STST	Hop for distance, involved to uninvolved (%)	99.4	6.7	87.2	111.0	.7943
PATS	Hop for distance, involved to uninvolved (%)	98.9	6.2	85.5	109.0	
STST	4-hop crossover test, uninvolved	609.9	224.9	154.9	975.4	1.000
PATS	4-hop crossover test, uninvolved	644.2	132.7	442.0	825.5	
STST	4-hop crossover test, involved	609.9	223.8	177.8	1038.9	.7281
PATS	4-hop crossover test, involved	633.1	140.4	401.3	833.1	
STST	Crossover hop, involved to uninvolved (%)	99.6	9.3	78.5	114.8	.4513
PATS	Crossover hop, involved to uninvolved (%)	98.0	4.6	86.8	104.0	
STST	40-yd sprint, first trial	6.0	1.8	4.9	11.1	.9020
PATS	40-yd sprint, first trial	5.5	0.7	4.5	7.1	
STST	40-yd sprint, second trial	5.9	1.6	4.9	10.4	.5181
PATS	40-yd sprint, second trial	5.7	0.7	4.9	7.4	

FIGURE 3. Side bridge: performed by using abdominal and hip muscles to hold the body in a side-lying plank position with the lower elbow and feet being the only points of contact.

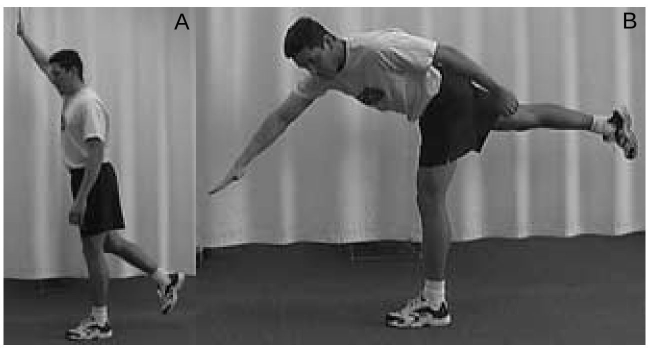

FIGURE 4. Single-leg stand windmill touches: performed by standing on 1 leg, then rotating the trunk and flexing the hips to bring the hand down in front of the lower leg.

contractions of the muscles that control hip and pelvis movement. This also allows the lower-extremity muscles to function at a higher velocity while maintaining a protected range of motion. Other authors have hypothesized that the ability to control the lumbopelvic region during higher-speed skilled movements may prevent hamstring injury.[11,14,24,25] Our study supports that this type of program is effective in preventing reinjury after an acute hamstring strain, but because no measurements related to the assessment of trunk stabilization and neuromuscular control were made, it is not possible to conclude that the results were due to changes in trunk stability, coordination, or other aspects of motor control. More research is needed to quantify changes in muscle activation and response times of the trunk and pelvis that may occur from these types of rehabilitation programs.

The difference in reinjury rates between these groups could not be attributed to degree of initial injury. In the STST group, 7 athletes (64%) suffered a first-degree strain, while the other 4 (36%) suffered a second-degree strain. In the PATS group, 5 athletes (38%) suffered a first-degree strain, while the other 8 athletes (62%) suffered a second-degree strain. The difference between the percentages of first-degree injuries for the 2 groups is 25% and the 95% confidence interval is –14% and 64%, showing no difference in injury severity between groups.

The average time required to return to sports for athletes in the STST group was 37.4 days (SD, 27.6 days), while the average for athletes in the PATS group was 22.2 days (SD, 8.3 days). This was not a statistically significant difference ($P = .2455$). Therefore, the difference in reinjury rate between groups could not be attributed to a longer rehabilitation time either.

It was also shown that the difference in reinjury rate at 2 weeks after return to sport could not be attributed to time to return to sport ($P = .789$). The average time required to return to sports for athletes from both groups who subsequently reinjured ($n = 6$) was 35.2 days (SD, 26.7 days), while the average for athletes who did not reinjure ($n = 18$) was 25.4 days (SD, 19.5 days). Therefore, successful return to sports without reinjury was not due to a longer rehabilitation time.

Statistical analysis of the functional testing profile data did not show any difference between the 2 rehabilitation groups or between the reinjury and nonreinjury groups. These results also suggest that these particular functional tests have a limited ability to predict which athletes with a hamstring injury are ready to safely return to sports. More research is needed to identify clinical tests that can predict when athletes can return to sports with minimal risk of reinjury after sustaining a hamstring strain.

At the current time, we are unaware of any prospective randomized studies comparing acute hamstring strain rehabilitation programs. This prevents us from directly comparing our results with those of others. However, our findings are similar to the results demonstrated by Holmich and colleagues.[12] Both studies indicate that exercises that aim to improve neuromuscular control are more effective for rehabilitating pelvic muscle injuries than stretching exercises. Holmich et al[12] demonstrated that individuals with longstanding adductor pain had less pain and improved sports performance after undergoing an active rehabilitation program that aimed at improving strength and coordination of the muscles acting on the pelvis, as compared to individuals who completed a rehabilitation program consisting of modalities and stretching. Croiser et al[7] showed that correction of concentric and eccentric muscle strength deficits and muscle imbalances between the hamstrings and quadriceps allowed subjects with acute and recurrent hamstring strains to return

TABLE 10. Statistical analysis of functional testing between individuals who were reinjured within 2 weeks of return to sports group (n = 6) and those who were not (n = 18). *P* values based on Wilcoxon's rank sum test. Hop tests are measured in cm and sprinting tests are measured in seconds.

Group	Test	Mean	SD	Minimum	Maximum	*P* Value
No reinjury	Hop for height, uninvolved	38.3	9.3	19.1	52.1	.4424
Reinjured	Hop for height, uninvolved	35.4	12.8	20.3	57.2	
No reinjury	Hop for height, involved	37.9	8.6	19.1	49.5	.5258
Reinjured	Hop for height, involved	36.0	13.7	17.8	58.4	
No reinjury	Hop for height, involved to uninvolved (%)	100.6	15.8	77.8	134.5	1.0000
Reinjured	Hop for height, involved to uninvolved (%)	101.6	15.8	87.5	131.8	
No reinjury	Hop for distance, uninvolved	165.5	36.1	71.1	207.0	.9734
Reinjured	Hop for distance, uninvolved	165.0	41.8	96.5	216.7	
No reinjury	Hop for distance, involved	161.0	33.5	73.2	205.7	.7138
Reinjured	Hop for distance, involved	171.1	48.3	96.5	240.5	
No reinjury	Hop for distance, involved to uninvolved (%)	97.9	6.3	85.5	109.0	.0718
Reinjured	Hop for distance, involved to uninvolved (%)	103.1	4.9	97.3	111.0	
No reinjury	4-hop crossover test, uninvolved	621.8	167.2	154.9	826.8	.6648
Reinjured	4-hop crossover test, uninvolved	668.5	216.9	349.8	977.1	
No reinjury	4-hop crossover test, involved	602.6	160.9	177.8	833.1	.4047
Reinjured	4-hop crossover test, involved	682.2	233.2	360.7	1038.9	
No reinjury	Crossover hop, involved to uninvolved (%)	97.7	7.6	78.5	114.75	.1336
Reinjured	Crossover hop, involved to uninvolved (%)	101.8	4.0	97.6	106.3	
No reinjury	40-yd sprint, first trial	5.9	1.5	4.5	11.1	.6489
Reinjured	40-yd sprint, first trial	5.5	0.7	4.9	6.9	
No reinjury	40-yd sprint, second trial	6.0	1.4	4.9	10.4	.2479
Reinjured	40-yd sprint, second trial	5.5	0.8	4.9	6.9	

to sports at preinjury levels with subjective reduction in pain.[7] Progressive agility and trunk stabilization drills do involve a combination of concentric, eccentric, and isometric contractions of the hamstring muscles in various length-tension positions. Although isokinetic testing was not carried out in our study, it is possible that early initiation (phase 1) of concentric, eccentric, and isometric contractions in the PATS group helped to prevent reduction in strength or muscle imbalances without adversely affecting the scar tissue. The STST group did not start eccentric contractions (non–weight-bearing foot catches) until phase 2.

Our study has recognized limitations. One major limitation is that we do not have direct evidence that the PATS group had less reinjuries because of improved neuromuscular control or trunk stabilization. We did not measure the changes that were hypothesized to occur as a result of our interventions. We are currently investigating how hip and trunk muscle activation, timing, and sequencing is affected in healthy subjects who undergo a 6-week training program consisting of the exercises in the PATS program. Another limitation was that patients were required to self-report their exercise compliance, abstinence from other treatment modalities, and injury recurrences at the 1-year follow-up call. We tried to minimize self-reporting bias by informing subjects during the initial evaluation that there would not be any personal consequence of the reports. Two subjects who reported less than 70% compliance with the exercise program were eliminated from the study, but chose to continue receiving free treatment. Another limitation of our study is that 1 of the authors was responsible for supervising subjects' rehabilitation program and performing evaluative testing. Although this provided consistency for instruction and testing, it prevented blinding during the rehabilitation and testing.

There was also a large range in the number of days (10-95) needed for return to sports by the individual subjects. By using the Wilcoxon rank sum test, and thus treating these data as nonparametric data, we have decreased the chance that differences occurred due to large variations within the variables.

We did not randomize subjects based on grade of injury. Classification systems categorize muscle injuries that produce pain, while muscle output remains at near full strength, as first-degree strains, muscles injuries that produce weakness and pain as second-degree strains, and injuries that result in pronounced weakness and a palpable defect as third-degree strains.[6] The severity of hamstring strains ranges on a continuum from very mild to very severe. Research has not demonstrated a clear relationship between classification of injury and incidence of reinjury or time needed to return to sport. For this reason, the subjects were not stratified by the muscle strain classification system shown in Table 3. Subjects were given a grade using the strain classification, but this was only used for postrehabilitation comparisons.

CONCLUSION

A rehabilitation program consisting of progressive agility and trunk stabilization exercises is effective in promoting return to sports and in preventing injury recurrence in athletes who have sustained an acute hamstring strain. This program allows athletes to return to sports at less risk for acute reinjury than those who complete a more traditional isolated stretching and strengthening exercise program.

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