©Journal of Sports Science and Medicine (2011) **10**, 655-664
http://www.jssm.org

Research article

Improving functional performance and muscle power 4-to-6 months after anterior cruciate ligament reconstruction.

Sabrine Souissi [1,6], Del P. Wong [2]✉, Alexandre Dellal [1,3,7], Jean-Louis Croisier [4], Zied Ellouze [5] and Karim Chamari [1,6]

[1] Tunisian Research Laboratory ''Sport Performance Optimisation" - National Centre of Medicine and Science in Sport (CNMSS) - El Menzah, Tunisia, [2] Department of Health and Physical Education, The Hong Kong Institute of Education, Hong Kong, [3] Olympique Lyonnais FC (soccer), [4] Department of Motricity Sciences, Liège, Belgium, [5] Aspetar-Orthopeadic and Sports Medicine Hospital, Doha, Qatar, [6] ISSEP, Ksar-Saïd, University of Manouba, Tunisia, [7] Santy Orthopedicae Clinical, Sport Science and Research Department, Lyon, France

Abstract

The purpose of this study was to examine the effects of 8-week retraining programs, with either two or three training sessions per week, on measures of functional performance and muscular power in athletes with anterior cruciate ligament reconstruction (ACLR). Sixteen male athletes were randomly assigned to two groups after ACLR: a functional training group (FTG, n = 8) training 2 intense sessions per week (4hrs/week), and a control group (CG, n = 8) training 3 sessions per week with moderate intensity (6hrs/week). The two groups were assessed at four and six months post-ACLR and the effects of retraining were measured using the following assessments: the functional and the muscular power tests, and the agility T-test. After retraining, the FTG had improved more than the CG in the operated leg in the single leg hop test (+34.64% vs. +10.92%; large effect), the five jump test (+8.87% vs. +5.03%; medium effect), and single leg triple jump (+32.15% vs. +16.05%; medium effect). For the agility T-test, the FTG had larger improvements (+17.26% vs. +13.03%, medium effect) as compared to the CG. For the bilateral power tests, no significant training effects were shown for the two groups in the squat jump (SJ), the counter movement jump (CMJ) and the free arms CMJ (Arm CMJ). On the other hand, the unilateral CMJ test with the injured and the uninjured legs showed a significant increase for the FTG with respect to CG ($p < 0.05$). The present study introduces a new training modality in rehabilitation after ACLR that results in good recovery of the operated limb along with the contra-lateral leg. This may allow the athletes to reach good functional and strength performance with only two physical training sessions per week, better preparing them for a return to sport activity at 6 months post-ACLR and eventually sparing time for a possible progressive introduction of the sport specific technical training.

Key words: ACL reconstruction, knee injury, retraining, agility, strength testing, power testing.

Introduction

Anterior cruciate ligament (ACL) rupture is a serious knee injury sustained by athletes during sport and leisure time activities. The risk of ACL injury is significantly greater in individuals during pivoting and cutting movements (Dye et al., 1998). Athletes often find it difficult to return to full function after injuring the ACL, and frequently surgery is carried out to re-establish joint stability. However, it has been suggested that, after surgery the ability to perform functional activities and balance may be decreased (Noyes et al., 1991), and deficits have been reported in the muscular and sensory processes after reconstructive surgery (Ben Moussa et al., 2008; Legnani et al., 2010).

In this context, the ultimate goal after ACL reconstruction (ACLR) and rehabilitation is to regain normal range of motion, knee joint stability, muscle strength, and neuromuscular control, which all contribute to normal functional performance (Tegner et al., 1986). These goals have to be achieved without jeopardising the healing graft while preventing the development of osteoarthritis (OA). Most studies reported the effects of the neuromuscular programs on decreasing the incidence of ACL injury among athletes as a preventive program (Myer et al., 2005; Nyland et al., 2010) or in increasing strength and function in healthy subjects especially in women (Chimera et al., 2004; Williams et al., 2001). Nevertheless, to the best of our knowledge, the latter programs' effects on the late post-operation phase of ACL rehabilitation or on improvement of performance have not been studied.

Rehabilitation following ACLR is commonly divided into two phases: (1) early (occurring immediately after ACLR mainly composed of sub-acute strengthening) and (2) late rehabilitation (functional progression towards returning to sport). Standardized ACL rehabilitation focuses on acute and sub-acute management with relatively stringent guidelines. These regard the progression of weight bearing, improvement of range of motion, and progressive introduction of specific types of exercises through the rehabilitation phase (Wilk et al., 2003). Conversely, the final phases of rehabilitation are typically more general, with more global categorizations of appropriate exercises and progressions, without specific milestones for when it is safe to introduce risky and high-joint-loading activities, and also with the goal to transit the athlete after ACLR from the ability to perform daily activities to proficiency with higher level sport-related activities (Kvist, 2004; Wilkerson et al., 2004). Standardized rehabilitation exercises are initially performed at slower speed, with low to moderate forces, and often in single plane of motion and with later introduction of plyometrics and agility at 5 and 6 months, respectively (Beynnon et al., 2005; Edson, 2003). In the context of rehabilitation, accelerated return to athletics activities is encouraged (Myer et al., 2006). In late phase of rehabilita-

Received: 31 March 2011 / Accepted: 05 September 2011 / Published (online): 01 December 2011

tion, when athletes may be prepared to perform more functional training to better prepare for sport competition, they may also present deficits (in the injured leg or the balance between the injured and contra-lateral leg) that limit their potential for safe integration into full competitive sports (Myer et al., 2006). This phase is supposed to be organized to help systematic transition of the athlete through return to sport training in an efficacious manner (Myer et al., 2006).

In the context of regular training with healthy subjects, the inclusion of intense exercises such as plyometrics, high intensity strength contractions along with agility drills, could lead to improved general functional performances without threatening knee safety (Adams et al., 1992; Potteiger et al., 1999; Wrobble and Moxley, 2001).

Several studies report the use of various assessments to evaluate functional outcomes, such as hopping tests (Beynnon et al., 2005; Hamilton et al., 2008; Noyes et al., 1991), agility tests (Paule et al., 2000), and vertical jumps tests (Lange and Bury, 2002). These tests are also used commonly in field or clinical settings to assess the progress made in a training program or to determine the level of recovery after lower extremity injury or surgery, especially after ACLR. With respect to training frequency, rehabilitation programs are performed for several sessions per week. Nevertheless, performing too many intense sessions could lead to over-reaching or higher risk of injury or re-injury (Myer et al., 2006). Clinical experience suggests that a subject should tolerate 2 sessions at a specific intensity without any adverse responses before the intensity of the program is progressed (Adams et al., 1992). In this context, performing plyometrics and intense exercises only twice per week allows sufficient recovery between workouts (Adams et al., 1992; Chu, 1995) and possibly induces effective training stimuli increasing the outcome of training with such a low training frequency.

Therefore, the purpose of the present study was to examine the effects of an 8-week retraining program (from the 4th to 6th month post-ACLR) on measures of functional performance and muscle power in athletes with ACLR. It was hypothesised that the intense training program implemented only twice per week (4hrs/week) would result in significant improvements in performance in horizontal and vertical jump, agility, and muscle power as compared to a standardized rehabilitation program with 3 training sessions per week (6hrs/week).

Methods

Subjects

Twenty-four male athletes with unilateral injury and ACLR with patellar tendon, who had previously played competitive sports, including contact and pivoting sports, at regional or national levels, were recruited for post-surgical intervention from the orthopaedic department (Table 1). Exclusion criteria were applied when subjects had additional injury or previous surgery to the lower extremities (with the exception of partial meniscal injury) or with pain or swelling at 4 months post-operation. The study was conducted according to the Declaration of Helsinki and the protocol was fully approved by the Clinical Research Ethics Committee of the National Center of Medicine and Science in Sport before the commencement of the assessments. Written informed consent was received from all subjects after a detailed explanation about the benefits, and risks involved with this investigation. Subjects were told that they were free to withdraw from the study at any time without penalty. After application of intra-operative exclusion criteria, 16 subjects continued the rehabilitation and returned for the follow-up examination. No subjects experienced setbacks with this rehabilitation study causing them to drop out. Subjects were randomly assigned to two groups: a functional training group (FTG, n = 8) and a control group (CG, n = 8). At 4 months post-ACLR, there were no significant differences between the FTG and the CG for any of the characteristics of the subjects (Table 1).

Rehabilitation and training procedures

Standardized postoperative rehabilitation

All subjects underwent a standardized post-ACLR physiotherapy protocol supervised by the same group of six physiotherapists. During the first 3 months, the training included electrostimulation, range of motion improvement, proprioception and coordination exercises, focusing on neuromuscular control of the involved knee. Running was allowed when the quadriceps deficit measured by isokinetic test (Cybex; Cybex Norm (6000, Manufacturer, Ville, USA)) in the involved knee was less than 35% with respect to contralateral leg (Davies, 1987; Rochcongar 2004), rather than after a fixed post-surgery time period of 12 weeks. Functional training and plyometrics exercises were progressively authorized at 4 months post-surgery (16 weeks) after some criteria were applied, such as: symmetry (isokinetic deficit under 70% of the contralateral side (Edson et al., 2003; Rochcongar 2004)), ability to hop on one leg without pain, no effusion or swelling, and attainment of full range of motion evaluated by clinical examination (Gerber et al., 2006; Gobbi et al., 2002). Further details on the rehabilitation program have been described in previous studies (Cascio et al., 2004; Myer et

Table 1. Characteristics of the subjects at 4 months post-surgery.

Variables	FTG (n=8)	CG (n=8)
Age (years)	21.7 (3.0)	21.5 (4.1)
Height (m)	1.77 (.09)	1.80 (7.9)
Body mass (kg)	73.4 (7.8)	75.4 (5.0)
Time between injury to surgery (weeks)	11.6 (7.7)	12.6 (14.7)
Time post-surgery to rehabilitation (weeks)	3.1 (1.7)	2.2 (1.5)
Sport practice (Football/Other)	5/3	6/2
Leg injured (left/ right)	5/3	4/4
Leg injured (left/ right)	4/4	7/1
Presence of partial meniscal repair (left/right)	1/7	1/7

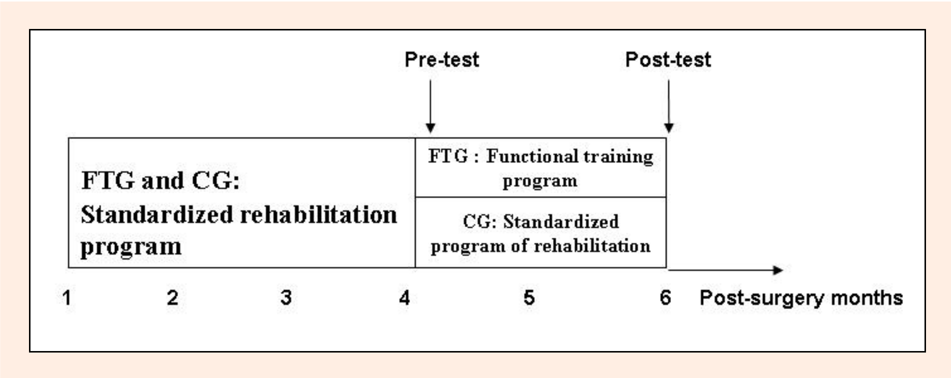

Figure 1. **Study logistics of subjects in the two groups.**

al., 2006).

Rehabilitation protocols

The 2 groups were tested at 4 and 6 months post-surgery (pre-test and post-test) by an experienced physiotherapist who was blinded to the present study protocol design (Figure 1).

The FTG was supervised by a fitness coach and the CG was supervised by a physiotherapist and the 2 groups were under supervision and responsibility of the physical physician at the Centre of Medicine and Science in Sport and Exercise. A physical physician performed the joint stability follow-up by clinical testing. The subject in each group with a partial meniscal repair had no pain or joint problem during the rehabilitation.

The CG did not participate in any exercises performed by the FTG, but their rehabilitation was monitored by the six aforementioned physiotherapists following the standardized rehabilitation protocol, i.e., 3 sessions per week (6hrs/week) (consisting of running and strengthening, a few plyometrics exercises with low intensity and slow progression, very few exercises of directional changing but no horizontal jump nor agility exercises (Table 2). The FTG participated twice per week in the functional training program (4hrs/week) including: a variety of intense, more aggressive and complex exercises designed to specifically increase neuromuscular control, muscle strength and power, proprioception, speed, and agility of the lower limbs, combined with an aerobic running training (Table 3). These exercises were gradually and carefully progressed with low to high intensity. For each exercise the introduction of more distance, time or height and difficulty was progressively introduced. As tolerance improved, the subject advanced to a more intense exercise. The safety and efficacy of adding intense exercises were fully monitored. These exercises accompanied by extensive verbal feedback to help the athletes to develop safe movements. The elements of this program were

Table 2. **Training protocol for the control group (CG).**

Week	Exercises			
	Strengthening	**Jumps**	**Speed**	**Proprioception**
1	Press 2-legs 3*50 1-leg curl 3*50 Chair 5*20	Forward barrier jump 2-legs 1*20 (50cm)		Balance with injured leg on unstable circle platform 10*15s
2	Press 2-legs 3*50 Injured leg curl 3*50 Chair 7*20	Forward barrier jump 2-legs 1*20 (50cm)		Balance with injured leg on unstable circle platform 10*15s
3	Press injured leg 3*50 Injured leg curl 3*50 Chair 5*30	Forward barrier jump Non injured leg 1*20 Injured leg 1*20 (50cm)	Moderate speed run forward 5*10m	Balance with injured leg on unstable circle platform 10*15s
4	Press injured leg 3*50 Injured leg curl 3*50 Chair 7*30	Forward barrier jump Non injured leg 1*20 Injured leg 1*20(50cm)	Moderate speed run backward 5*10m	Balance with injured leg on unstable circle platform 10*15s
5	Press injured leg 3*50 Injured leg curl 3*50 Chair 5*40	Lateral barrier jump 2-legs 1*20 (50cm)	High speed run forward 5*10m+180°turn	Balance with injured leg on unstable rectangular platform 10*15s
6	Press injured leg 3*50 Injured leg curl 3*50 Chair 7*40	Lateral barrier jump 2-legs 1*20 (50cm)	High speed run backward 5*10m+180°turn	Balance with injured leg on unstable rectangular platform 10*15s
7	Press injured leg 3*50 Injured leg curl 3*50 Chair 5*50	Lateral barrier jump Non injured leg 1*20 Injured leg 1*20 (50cm)	Lateral sprint 5*10m	Balance with injured leg on unstable rectangular platform 10*15s
8	Press injured leg 3*50 Injured leg curl 3*50 Chair 7*50	Lateral barrier jump Non injured leg 1*20 Injured leg 1*20 (50cm)	Forward sprint+180°turn+ backward sprint 5*10m	Balance with injured leg on unstable rectangular platform 10*15s

Add 5kg in leg press and 2kg in leg curl+chair every 2 weeks. Charge depending on individual capacity: Press (between 80-100 kg for 2 legs, 40-50kg for 1 leg). Leg curl+chair (between 40-50kg).

Table 3. Training protocol for the functional training group (FTG).

Week	Exercises			
	Aerobic	Jumps/hops	Speed+ agility	Proprioception
1	2*10'(60-70%HRmax) 3*10'(60-70% HRmax)	Double leg vertical forward hops (3*10) Double leg vertical backward hops(3*10)		Jump with 2-legs in trampoline +floor landing 2*10 Jump with 2-legs in trampoline + floor landing 3*10
2	1*20'(70-75% HRmax) 1*25'(70-75% HRmax)	Double leg vertical forward + backward hops (3*10) Single leg vertical hops 3*10	Moderate speed run forward 5*10m Moderate speed run backward 3*10m Moderate speed run forward 8*10m Moderate speed run backward 5*10m	Jump with 1-leg in trampoline + floor landing on 1-leg 3*5 rope jumping with 2legs
3	1*15'(80% HRmax) 2*15'(80% HRmax)	Single leg forward+backward hops 3*10 Single leg lateral,left+right hops 3*10	Moderate speed run 10m forward+2 one leg hop forward*5 Moderate speed run 10m forward +2one leg hop backward*5	Jump with 1-leg (left-right) in trampoline +floor landing on 1-leg 3*10 Rope jumping with 2-legs forward +backward 3*10
4	1*12'(80-85% HRmax) 2*12'(80-85% HRmax)	Single leg vertical hops 5*10+180° turn Single leg square*5	High speed run 10m backward +2one hop forward *5 High speed run 10m backward+2 one leg backward *5	Rope jumping alternating 2 legs 3*20 Rope forward jumping alternating 2-legs 3*20
5	1*6'(85-90% HRmax) 2*6'(85-90% HRmax)	Leg even surface*5 Scissors jumps 3*5	High speed run in slalom between 12cones(4feet space)*5 High speed run in slalom between 12cones(5feet space)*5	2-legs jump from box(30cm)+floor landing on 2legs*8 1-leg jump on box(15cm)3*10 Floor to box
6	3*6'(85-90% HRmax) 1*4'(90-95% HRmax)	Single-leg Triple hop*5	Sprint in slalom in shuttle runs*3 Sprint in slalom in shuttle runs*5	2-legs jump from box(40cm)+floor landing on 2legs*8 1-leg jump on box(20cm)5*10 Floor to box
7	2*4'(90-95% HRmax) 3*4'(90-95% HRmax)	5-jump start left *3 5-jump start right *3	Sprint in slalom in shuttle runs+jump bench*2 Sprint in slalom in shuttle runs+jump bench*3	Landing from box (30cm)on 1leg*5 1-leg jump on box(30cm)5*10 Floor to box
8	4*4'(90-95% HRmax)	Single-leg Triple hop*5 5-jump start left *2 5-jump start right *2	8-form run to the right *2 8-form run to the left*2	Landing from box (40cm)on 1leg*5 1-leg jump on box(40cm)10*5

For all exercises with one leg, subject performed 2 sets less than with the uninjured leg. Recovery: 30s between sets and 2' between exercises for jumps, speed and proprioception exercises. In hopping exercise, subject hop as far as possible (maximum distance)

previously reported in the literature (Hewett et al., 1996). Training was performed under direct supervision of a fitness coach guiding the subjects on how to perform each exercise.

Each training session began with a warm up of 20-min (including 10-min of active static stretching, and lower limbs exercises). The plyometric training component progressively emphasized double, then single-leg movements throughout the training sessions. Nevertheless, the uninjured leg was trained with fewer sets than the injured side. The goal was to achieve pre-injury level of strength for both legs. The plyometrics exercises were initiated when the patient could tolerate them without adverse reactions (Chmielewski et al., 2006). Subjects were trained on flat and regular ground wearing adequate footwear.

Functional tests

Three functional tests the single leg hop (SLH), the single leg triple hop (SL3H) and the five jump test (5JT) were used to evaluate general lower limb function. During these tests, the subjects performed the first trial with the injured leg, followed by the uninjured one. Firstly, the modified (SLH) as reported by Tegner et al. (1986), allowing the use of the arms for accelerating the jump, was carried out. The single-leg hop for distance scores are commonly expressed as a limb symmetry index (LSI). Noyes et al. (1991) considered an LSI score over 85% to be normal. Secondly, the (SL3H) test was performed by the subjects (Hamilton et al., 2008). The SLH and the SL3H tests were performed 3 times with each leg. Finally, the (5JT) as described by Chamari et al. (2008) was performed by the subjects. The 5JT consist of 5 consecutive strides with joined feet position at the start and end of the jumps. From the starting position, the subject had to directly jump to the front with one leg and after the first 4 strides, i-e, alternating left and right feet for 2 times each, he had to perform the last stride and end the test again

Table 4. Reliability of tests employed in this study.

Pooled data (pre-test plus post-test, all groups)		ICC (inter-subject reliability) ICC	95% Confidence interval	Intra-subject reliability
Single leg hop (m)	Injured leg	.98	.97-.99	.95
	Uninjured leg	.98	.96-.99	.93
Single leg triple hop (m)	Injured leg	.99	.98-.99	.85
	Uninjured leg	.99	.98-.99	.96
Five jump test (m)	Starting with injured leg	.97	.95-.98	.91
	Starting with uninjured leg	.99	.98-.99	.98
Agility T-Test (sec)		.99	.98-.99	.96
Squat jump (SJ)(cm)		.98	.97-.99	.95
Counter movement jump (CMJ)(cm)		.99	.98-.99	.96
Arm CMJ (cm)		.96	.93-.98	.89
CMJI (cm)		.94	.90-.96	.84
CMJNI (cm)		.93	.89-.96	.82

with joined feet. In the present investigation each subject performed the 5JT starting twice with the injured leg followed by twice with the uninjured leg. The best performance (as indicated by the distance) of each of the three tests was used in the data analysis. All tests were separated by one minute recovery.In case of unsuccessful trial, e.g. the subject felt that he did not perform the test appropriately, it was possible to re-perform the test again, but this seldom occurred.

Agility test

The agility "T" test is a standard test for the assessment of agility. As described by Sporis et al. (2010), it is used to determine speed with directional changes and is composed of forward sprinting, left and right side shuffling, and backward running (Miller et al., 2006; Pauole et al., 2000; Sporis et al., 2010). The agility "T" test performance was measured by a photocell electronic timing system (Brower Timing, USA). Subject performed 3 trials with 2 minutes of rest in-between, and the fastest one was used for analysis.

Muscular power test

The subjects performed 4 jumping protocols evaluating power on a force platform (Quattrojump, Kistler, Switzerland). The first protocol consisted of jumping with both legs from a fixed semi-squat position with the hands held at the hips, i.e. squat jump (SJ). The second vertical jump test was a countermovement jump either with the hands at the hips (CMJ). The subject was encouraged to react as quickly as possible on the platform, to jump as high as possible and land on their feet. The last jump test was a CMJ with free arm swing (Arm CMJ) (Chamari et al., 2008). After these tests, subjects were assessed for their ability to perform a unilateral vertical jump CMJ with hands at their sides. Each subject stood with one leg on the force plate and jumped as high as possible, landing on the same foot. They began with the uninjured leg

Table 5. Functional, muscle power, and agility performance from 4 to 6 months post-surgery.

Variables	Group	Pre-test	Post-test	% progress	Effect size based on the % progress (value/classification)
Single leg hop (injured) (m)	FTG	1.45 (.26)	1.91 (.18) *	34.64 (24.16)	1.38 /Large
	CG	1.69 (.12)	1.77 (.16)	10.92 (10.42)	
Single leg hop (uninjured) (m)	FTG	1.77 (.15)	2.02 (.11) *†	14.27 (4.97)	2.66 /Large
	CG	1.85 (.16)	1.88 (.11)	3.69 (2.64)	
Single leg triple hop (injured leg) (m)	FTG	4.14 (.78)	5.28 (.40) *	32.15 (30.57)	.71 /Medium
	CG	4.38 (.48)	5.04 (.15) *	16.05 (9.54)	
Single leg triple hop (uninjured leg) (m)	FTG	5.04 (.51)	5.79 (.34) *	15.78 (13.24)	.71 /Medium
	CG	5.03 (.57)	5.39 (.29)	7.55 (9.70)	
Five jump test (starting with injured leg) (m)	FTG	10.36 (.93)	11.25 (.83) *	8.87 (6.14)	.73 /Medium
	CG	10.18 (.73)	10.67 (.57)	5.03 (4.15)	
Five jump test (starting with uninjured leg) (m)	FTG	10.26 (.93)	11.00 (1.06)	7.32 (4.02)	.43 / Small
	CG	10.07 (.83)	10.60 (.78)	5.43 (4.74)	
Agility T-Test (sec)	FTG	11.92 (.59)	10.18 (.39) *†	17.26 (7.86)	.52 /Medium
	CG	11.24 (.60)	10.86 (.71) *	13.03 (8.37)	
Squat jump (cm)	FTG	38.82 (5.79)	43.15 (5.24)	12.28 (12.91)	.57 /Medium
	CG	38.58 (4.77)	40.8 (4.76)	6.50 (6.50)	
Counter movement jump (CMJ)(cm)	FTG	41.61 (5.99)	43.57 (4.62)	6.71 (6.16)	.16 /Trivial
	CG	40.62 (4.12)	42.95 (4.44)	5.83 (4.98)	
Arm CMJ (cm)	FTG	50.97 (5.23)	52.91 (3.62)	3.72 (5.37)	.80 /Large
	CG	48.95 (5.49)	49.06 (4.93)	.61 (1.24)	
CMJI (cm)	FTG	23.18 (4.35)	28.72 (2.12) *	27.54 (24.55)	1.11 /Large
	CG	25.31 (3.77)	26.53 (3.04)	6.54 (10.71)	
CMJNI (cm)	FTG	27.93 (3.85)	31.18 (1.85) *†	13.34 (12.31)	1.49 /Large
	CG	28.32 (3.18)	27.97 (3.54)	.33 (.79)	

* Significant difference ($p < 0.05$) between 4 and 6 months.
† Significantly different from control group (CG) ($p < 0.05$).

(CMJNI), followed by the injured leg (CMJI). Peak height of the jumps was recorded. One minute recovery was allowed in-between jumps and each jump was repeated 3 times.

Statistical analysis

The mean and standard deviation (mean ± SD) were calculated for all tests. Multivariate analysis of variance (MANOVA) was used to examine the differences in performance with two factors (GROUP x training intervention). Follow-up pairwise comparison using Bonferroni-corrected method was used when appropriate.

Test-retest reliability of the each assessment was determined by intraclass correlation coefficient (ICC) with a 95% confidence interval. All data were initially analysed using Microsoft Excel (Microsoft, Redmond, Washington). Statistical analysis was completed using SPSS version 10.0 (SPSS Inc, Chicago, Illinois). Effect sizes (Coden's *d*) and statistical power were calculated to determine the practical difference between the FTG and the CG. Effect size values of 0-0.19, 0.20-0.49, 0.50-0.79, and 0.8 and above were considered to represent trivial, small, medium, and large differences, respectively (Cohen, 1988). Statistical power greater than 0.84 was considered optimal (Muller and Benignus, 1992). The level of significance was set at $p \leq 0.05$.

Results

The statistical power of the present study was 0.85. The reliability (ICC) of the following tests: the horizontal jump tests– forward hop tests- (SLH, SL3H, and 5JT), the vertical jump tests (SJ, CMJ, Arm CMJ, CMJI, CMJNI), and the agility "T" test was excellent (Table 4).

The functional training group (FTG) showed higher improvements than CG in the SLH with the injured leg (+34.64% vs. +10.92%, large effect, Table 5), the 5JT starting with the injured leg (+8.87% vs. +5.03%, medium effect), SL3H with the injured leg (+32.15% vs. +16.05%, medium effect). Concerning the uninjured leg, The FTG had larger improvements in the SLH test (+14.27% vs. +3.69%, large effect) and the SL3H (+15.78% vs. +7.55%, medium effect) as compared to the CG.

The single leg hop scores are expressed as a limb symmetry index. According to the cut-off value (85%) suggested by Noyes et al. (1991), only 37.5% of the FTG subjects and 50% of the CG subjects were regarded as normal in the pre-test. The LSI increased to 87.5% for both groups in post-test after either training protocols. For the SL3H test, only 37.5% of the FTG and 62.5% of the CG had an LSI score higher than 85% in pre-test. In the post-test, all subjects in both groups presented an LSI score higher than 85%.

With regard to the agility "T" test, there was a significant difference between the FTG and the CG after training (+17.26% vs. +13.03%, $p<0.05$, medium effect).

For the muscular power assessed by vertical jumping, the CMJI test showed significantly increased performance for the FTG with respect to the CG (+27.54% vs +6.54%, large effect). Improvement was also observed in LSI after 8 weeks of training. The percentage of subjects with an LSI higher than 85% in the FTG increased from 50% to 87.5% compared to the CG who presented a decrease from 75% to 62.5%.

Discussion

The present study showed that from the 4th to 6th months post-surgery, the functional training program resulted in significantly greater improvements than the standardized rehabilitation program concerning the functional tests (the SLH injured, the SLH uninjured and the 5JT with injured leg), the CMJ with one leg, and the agility "T" test performance.

The SLH test is a measure of functional performance of the lower limb, allowing the evaluation of strength and confidence in the tested extremity. It has significant positive relationship to the subject's subjective knee function and it has been designed to reflect the demands of a high level of physical activity (Noyes et al., 1991). This is thus a good marker of training efficiency. A reduced hop distance has been reported in most subjects after ACL injury (Kvist, 2004; Toumi et al., 2004) and improvement has been found after various training programs (Tegner and Lysholm 1985). The present study is consistent with a previous study (Tegner and Lysholm 1985) in which a functional training protocol improved SLH distance and SL vertical jump in both legs. Conversely, the subjects in the CG still demonstrated impaired function of their lower limbs. The results of the present study echoed the suggestion by Nyland et al. (1994) that functional training could better improve the function of the reconstructed knee by more effective utilization of afferent neural input and more complete use of motor learning concept than the traditional rehabilitation program.

At the post-test, 87.5% of the FTG subjects had a normal LSI value (LSI higher than 85%) in the SLH test, whereas Wilk et al. (2003) found that only 43% of the studied subjects had a LSI score higher than 85% by 6.45 months post-surgery. Similarly, DeJong et al. (2007) found a LSI score below the safe range value for 31% of the subjects at 9-months post-surgery. Others studies have shown a LSI of 83 % at six months post-surgery (Keays et al., 2000). In the present study, a higher proportion of subjects reached normal/safe values for the SLH test by 6-months post-surgery, indicating the efficacy of the current functional training program. Although the difference in the functional performance between the injured and uninjured legs has not been shown to have a definite relationship with a propensity towards injury during athletic activities (Wilson et al., 1993), a difference of 10% or more can be considered to reflect a real difference in the capacity of performance and a possible threat for higher injury risk (Sapega, 1990).

The results of SL3H test showed that the two groups progressed significantly in the injured leg but only the FTG showed significant progress in their uninjured leg. The strength increase in the uninjured leg may have occurred due to compensation for the loss of function after the injury and subsequent surgical reconstruction and/or be a natural adaptation to the proposed program, which focused on both legs. In the CG, the improvements were largely dependent on subject's motivation, and the training of the uninjured leg might have been underestimated in the classical rehabilitation program. The advantage of the use of the unilateral SL3H (and SLH and jump tests) is that each leg can be evaluated independently, so that asymmetries may also be identified. For this test also, the FTG showed a higher proportion of subjects reaching normal values compared to the CG after 2 months training, which confirmed the efficiency of the FTG rehabilitation program.

A recent study (Chamari et al., 2008) proposed the 5JT performance as a practical alternative to estimate lower limb explosive power for particular athletes and to measure the function of stretch-shortening cycle. The 5JT may be regarded as a reliable, very useful, and simple testing tool that provides information about athletes stride power, which is considered as a crucial measurement in many running sport activities (Chamari et al., 2008). Moreover, Paavolainen et al. (1999) showed that this test is sensitive to training effects. FTG subjects' increased 5JT performance starting with the injured leg significantly more than CG, showing the efficacy of the functional training program performed in the improvement of stride power.

The agility of the subjects was assessed by the agility "T" test and the performance improved significantly more for the FTG group than the CG ($p<0.05$). Results indicated that the functional training program improved agility performance possibly due to better motor recruitment and/or neural adaptations. Indeed, Potteiger et al. (1999) reported that the agility improvements resulted from enhanced motor unit recruitment patterns. Such increase in agility is beneficial for athletes who perform quick movements while performing sport. Renfro (1999) measured agility testing using the "T" test after plyometric training while Robinson and Owen (2004) used vertical, lateral and horizontal plyometric jumps training and showed improvement in agility. Potteiger et al. (1999) have shown that plyometric training, when incorporated with a periodized strength training program, could contribute to the improvement of vertical jump performance, acceleration, leg strength, muscular power, and increased joint proprioception. Plyometrics drills usually involve starting, stopping, and direction changing in an explosive pattern (Young et al., 2001). It has been suggested that these movements are components that can assist in developing agility (Zatterstrom et al., 1992). The effect of a training program specifically targeted for speed enhancement on injury risk reduction is unknown. However, Heidt et al. (2000) showed that a speed and agility protocol is able to prevent injury, in terms of a reduction of lower extremity injuries in the trained female athletes by 98% when compared with athletes who did not go through such training. It has also been reported that speed training enhances speed performance and that the addition of plyometrics or resistance training can provide combinatory effects for increasing speed (Risberg et al., 1999). Neuromuscular training often induces increased power, agility and speed (Kraemer et al., 1998).

The 8-week functional training program signifycantly improved CMJI performance as compared to the training of control group. Relevant literature has shown that vertical jump performance can be improved through various types of training methods, such as resistance training (Baker, 1996), jumping (Wrobble and Moxley, 2001) and combination of plyometrics exercises and electrostimulation (Maffiuletti et al., 2000). It was suggested that enhanced jumping performance after plyometrics training was attributed to neural adaptation, i.e., the patterns of motor unit recruitment and muscle activities of agonists and antagonists (Kyrolainen, 1991).

The present study showed that neither groups demonstrated improvements in the SJ, the CMJ, and the Arm-CMJ. This is in agreement with Chimera et al. (2004) who demonstrated small and insignificant improvement in vertical jump height between plyometric and control groups among athletes. In addition, Luebbers et al. (2003) and Herrero et al. (2010) demonstrated no improvement immediately after a plyometric training but rather after a period of recovery of 4 weeks. However, these results contrasted those of Field (1991), who reported improvement in vertical jump after plyometric training program in athletes. It appears that these studies employed different frequency, intensity, duration and type of plyometrics exercises, which may explain the different training effects. In this context, vertical jumping, even if present in several sports, seems less relevant to general sport performance than horizontal hopping tests. Indeed, much more sports rely on horizontal displacements than vertical jumping.

The FTG group improved significantly more than CG in the horizontal single leg hop and the agility test, demonstrating its efficiency. Achieving higher improvements for vertical jumping could be attempted in future studies, even if it could be possible that a ceiling effect could be reached quite soon in ACLR rehabilitation programs for vertical jumping.

When designing a program, especially a high impact program, we need to be aware that one of the major long term sequel following ACL injury and surgery is the development of OA. Recent studies (Oiestad et al., 2010) found a 62% and 80% incidence of OA 10-15years after reconstruction. Several factors have been related to the development of OA including the presence of meniscal/chondral injury (Gillquist et al., 1999), weak quadriceps (Slemenda et al., 1997), and altered knee kinematics (Deneweth et al 2010). By ensuring good quadriceps strength and eccentric control, together with correct exercise technique and biomechanics, by training muscles actively to act as shock-absorbers (Bennell et al., 2008; Bennell et al., 2009), and by avoiding any further injury especially to the menisci we can minimize the development of OA. It is possible that we may reduce OA by wearing athletic shoes, and by working on predictable level surfaces.

The 8-week functional training program was developed using 2 training sessions per week (4hrs/week). From a physiological and psychological standpoint, four to six weeks of high intensity power training is an optimal duration for the central nervous system to be stressed without excessive strain or fatigue (Adams et al., 1992). The present study showed that this frequency and period seems to allow sufficient time to induce additional neuromuscular benefits on some functional and power performances such as the single leg hop test (horizontal and vertical), the five jump test and the agility. In this context, it could be interesting to study the effects of a training extension from 8 weeks to longer periods on the beneficial effects and the return to sport for the athletes after ACLR.

The present study showed that from 4 to 6 months post-ACLR, 2 physical training sessions a week (4hrs/week) of intensive training is at least comparable and even more effective (for some functional performances) than 3 sessions a week (6hrs/week) of relatively low intensity training. This could spare time for an eventual progressive introduction of sport specific technical training. Further research is needed to determine whether the implementation of an additional weekly intense session, i.e., 3 sessions of intensive training instead of 2, could lead to even higher neuromuscular adaptations. In this context, it has to be stressed that attention has to be paid to the safety of such a program, i.e., absence of any injury, joint/muscle pain and joint swelling, or OA which could threaten the rehabilitation process.

Conclusion

The present study provides evidence of the efficiency of functional training in knee rehabilitation and provides important information that is highly relevant to clinicians, physiotherapists, coaches and trainers who are in charge of the injured athletes during the later phase of the rehabilitation after ACLR.

The present study introduces a new training modality in rehabilitation after ACLR which results in better recovery of the operated limb along with the contra-lateral leg. This may allow the athletes to reach good functional and strength values with only two training sessions per week, better preparing them for a return to sport activity at 6 months post-ACLR.

Acknowledgments

The authors thank all the National Centre of Medicine and Science in Sport (CNMSS) physiotherapists, Nejib Tekaîa, Sofiene Khouja, Fathi Abid, Mourad Saddour and especially Sofiene Kasmi and Narjess Touati.

The authors also thank Dr. Andrew W. Smith for his English edit of this manuscript, the patients who participated in this study, Dr Mokhtar Chtara who helped in statistical analyses, Dr Mourad Hambli for his technical support and finally, Dr Moncef Ben Abid, Dr Anis Chaouachi and Dr Wassim Moalla, for their guidance in this study.

References

Adams, K., O'Shea, J.P., O'Shea, K.L. and Climstein, M. (1992) The effects of six week Of squat, plyometrics, and squat plyometric training on power production. *Journal of Applied Sports Science Research* **6,** 36-41.

Ben Moussa Zouita, A., Zouita, S., Dziri, C., Ben Salah, F.Z. and Zehi, K. (2008) Isokinetic, functional and proprioceptive assessment of soccer players two years after surgical reconstruction of the anterior cruciate ligament of the knee. *Annales de Réadaptation et Medecine Physique* **51,** 248-256.

Baker, D. (1996) Improving vertical jump performance through general, special, and specific training. *The Journal Strength and Conditioning Research* **10,** 131-136.

Bennell, K.L., Hunt, M.A., Wrigley, T.V., Lim, B.W. and Hinman, R.S. (2008) Role of muscle in the genesis and management of Knee Osteoarthritis. *Rheumatic DiseasesClinics of North America* **34(3),** 731-754.

Bennell, K.L., Hunt, M.A., Wrigley, Lim, B.W. and Hinman, R.S. (2009) Muscle and Exercise in the Prevention and management of Knee Osteoarthritis. *The Medical Clinics of North America* **93(1),** 161-177.

Beynnon B.D., Bennjamin, S., Johnson R.J., Abate, J.A., Nichols C.E., Fleming B.C., Poole, A. and Roos, H. (2005) Rehabilitation after anterior cruciate ligament reconstruction. A prospective, randomized, double-blind comparaison of programs administrered over 2 different time intervals. *The American Journal of Sports Medicine* **33(3),** 347-359.

Bobbert, M.F. and Van Shoest, A.J. (1994) Effect of muscle strengthening on vertical jump height: A stimulation study. *Medicine and Science in Sports and Exercise* **26,** 1012-1020.

Cascio, B.M., Culp, L. and Cogarea, A.J. (2004) Return to play after anterior cruciate ligament reconstruction. *Clinics Sports Medicine* 23: 395-408.

Chamari, K., Chaouachi, A., Hambli, M., Kaouech, F., Wissloff, U. and Castagna, C. (2008) The 5 jump test for distance as a field test to assess lower limb explosive power in soccer players. *The Journal of Strength and Conditioning Research* **22,** 994-950.

Chimera, N.J, Swanik, K.A., Swanik, C.B. and Straub, S.J. (2004) Effects of plyometric training on muscle activation strategies and performance in female athletes. *Journal of Athletic Training* **39,** 24-31.

Chmielewski, T.L, Myer G.D., Kauffman, D. and Tillman, S.M. (2006) Plyometric exercise in the rehabilitation of athletes: physiological responses and clinical application. *Journal of Orthopaedic and Sports Physical Therapy* **36(5),** 308-319.

Chu, D.A. (1995) Rehabilitation of the lower extremity. *Clinical Sports Medicine* **14,** 205-222.

Cohen, J. (1988) Statistical Power Analysis for the behavioural Sciences. Hillsdale, NJ: Erlbaum Associates.

Davies G.J. (1987) A compendium of isokinetics. *Clinical usage and rehabilitation technics*. 3rd Edition. S & S Publishers, Onalaska, WI.

DeJong, S.N., Van Caspel, D.R, Van Haeff, M.J. and Saris, D.B.F. (2007) Functional assessment and muscle strength before and after reconstruction of chronic anterior cruciate ligament lesions. *Arthroscopy* **23,** 21-28.

Deneweth, J.M., Bey, M.J., McLean, S.G., Lock, T.R., Kolowich, P.A. and Tashman, S. (2010) Tibiofemoral joint kinematics of the anterior cruciate ligament-reconstructed knee during a single legged Hop Landing. *The American Journal of Sports Medicine* **38(9),** 1820-1828.

Dye, S., Wojtys, E., Fu, F.H., Fithian, D.C. and Gillquist I. (1998) Factors contributing to function of the knee joint after injury of reconstruction of the anterior cruciate ligament. *The Journal of Bone and Joint Surgery* **80a,** 1380-1393.

Edson, C. (2003) Postoperative rehabilitation of the multiple-ligament reconstructed knee. *Operative Techniques in Sports Medicine*, **11(4),** 294-301.

Field, R.W. (1991) Off season plyometric conditioning for the collegiate soccer player. *National Strength Conditionning Association Journal* **13,** 27-28.

Gerber, J.P., Marcus, R.L., Dibble, L.E., Greis, P.E. and LaStayo, P.C. (2006) Early application of early application of negative work via eccentric ergometry following anterior cruciate ligament reconstruction. A case report. *Journal of Orthopaedic and Sports Physical Therapy* **36(5),** 298-307.

Gillquist, J. and Messner, K. (1999) Anterior cruciate ligament reconstruction and the long-term incidence of gonarthrosis. *Sports Medicine* **27(3),** 143-156.

Gobbi, A., Diara, A., Mahajan, S. Zanazzo, M. and Tuy, B. (2002) Patellar tendon anterior cruciate ligament reconstruction with conical press fit femoral fixation: 5 year results in athletes population. *Knee Surgery Sports Traumatology Arthroscopy* **10(2),** 73-79.

Hamilton, R.T., Shultz, S.J., Sshmitz, R.J. and Perrin, D.H. (2008) Triple hop distance as a valid predictor of lower limb strength and power. *Journal of Athletic Training* **43,** 144-151.

Heidt, R.S., Sweetermann, L.M., Carlonas, R.L., Traub, J.A. and Tekulve, F.X. (2000) Avoidance of soccer injuries with preseason conditioning. *The American Journal of Sports Medicine* **28,** 659-662.

Herrero, A.J., Martín, J., Martín, T., Abadía, O., Fernández, B. and García-López, D. (2010) Short-term effect of strength training with and without superimposed electrical stimulation on muscle strength and anaerobic performance. A randomized controlled trial. Part I. *Journal of Strength and Conditioning Research* **24(6),** 1609-1615.

Hewett, T.E., Stroupe, A.L., Nance, T.A. and Noyes, F.R. (1996) Plyometric training in female athletes. Decreased impact forces and increased hamstring torques**.** *The American Journal of Sports Medicine* **24,** 765-773.

Keays, S.L., Bullock-Saxton, J.E. and Keays, A.C. (2000) Strength and function before and after anterior cruciate ligament reconstruction. *Clinical Orthopaedic and Related Research* **373,** 174-183.

Kraemer, W.J., Duncan, N.D. and Volek, J.S. (1998) Resistance training and elite athletes: adaptations and program considerations. *Journal of Orthopaedic & Sports Physical Therapy* **28,** 110-119.

Kvist, J. (2004) Rehabilitation following anterior cruciate ligament injury: current recommendations for sports participation. *Sports Medicine* **34,** 269-280.

Kyrolainen, T.T., Komi, P.V. and Kim, D.H. (1991) Effects of power training on neuromuscular performance and mechanical efficiency. *Scandinavian Journal of Medicine and Sciences in Sports* **1,** 78-87.

Lange, B. and Bury, T. (2002) Preliminary study of jumping ability using the optojump system*. Biométrie Humaine et Anthropologie* **20(1-2),** 17-22.

Legnani, C., Ventura, A., Terzaghi, C., Borgo, E. and Albisetti, W. (2010) Anterior cruciate ligament reconstruction with synthetic grafts. *A review of literature. International Orthopaedic* **34,** 465-471.

Luebbers, P.E., Potteiger, J.A., Hulver, M.W., Thyfault, J.P., Carper, M.J. and Lockwood, R.H. (2003) Effects of plyometric training and recovery on vertical jump performance and anaerobic power. *Journal Strength and Conditioning Research* **17,** 704-709.

Maffiuletti, N.A., Gometti, C., Amiridis, I.G., Martin, A., Pousoon, M. and Chatard J.C. (2000) The effect of electrostimualation training and basketball practice on muscle strength and jumping ability. *International Journal of Sports Medicine* **21,** 437-443.

Miller, M.G., Herniman, J.J., Ricard, M.D., Cheatham, C.C. and Michael, T.J. (2006) The effect of 6 week plyometric training program on agility. *Journal of Sports and Sciences Medicine* **5,** 459-465.

Muller, K.E. and Benignus, V.A. (1992) Increasing scientific power with statistical power. *Nwurotoxic and Teratology* **14,** 211-219.

Myer, G.D., Paterno, M.V. and Hewett, T.E. (2004) Back in the game: a four-phase return to sport program for athletes with problem ACLS. *Rehabilitation Management* **17,** 30-33.

Myer, G.D., Ford, K.R., Palumbo, J.P. and Hewett, T.E. (2005) Neuromuscular training improves performance and lower extremity biomechanics in female athletes. *The Journal Strength and Conditioning Research* **19,** 51-60.

Myer, G.D., Paterno, M.V., Ford, K.R., Quatman, C.E. and Hewett, T.E. (2006) Rehabilitation after anterior cruciate ligament reconstruction: criteria based progression through the return to sport phase. *Journal of Orthopaedic & Sports Physical Therapy* **36,** 385-402.

Noyes, F.R., Babrber, S.D. and Mangine, R.E. (1991) Abnormal lower limb symmetry determined by function hop tests after anterior cruciate ligament rupture. *The American Journal of Sports Medicine* **19,** 513-518.

Nyland, J., Brosky, T., Currier, D., Nitz, A. and Caborn, D. (1994) Review of the afferent neural system of the knee and its contribution to motor learning. *Journal of Orthopaedic & Sports Physical Therapy* **19,** 2-11.

Nyland, J., Brand E. and Fisher B. (2010) Update on rehabilitation following ACL reconstruction. *Open Access Journal of Sports Medicine* **1,** 153-160.

Oiestad, B.E., Holm, I., Aune, A.K., Gunderson, R., Myklebust, G., Engebretsen, L., Fosdahl, M.A. and Risberg, M.A. (2010) Knee function and prevalence of knee osteoarthritis after anterior cruciate ligament reconstruction: a prospective study with 10 to 15 years of follow-up. *American Journal of Sports Medicine* **38(11),** 2201-2210.

Paavolainen, L., Hakkinen, K., Hamalainen, I., Nummela, A. and Rusko, H. (1999) Explosive strength training improves 5-km running time by improving running economy and muscle power. *Journal of Applied Physiology* **86,** 1527-1533.

Paule, K., Madole, K., Garhammer, J., Lacourse, M. and Rozenek, R. (2000) Reliability and validity of the t test as a measure of agility, leg power and leg speed in college aged men and women. *The Journal Strength and Conditioning Research* **14,** 443-450.

Potteiger, J.A., Lockwood, R.H., Haub, M.D., Dolezal, B.A., Alumzaini, K.S., Schroeder, J.M. and Zebas, C.J. (1999) Muscle power and fiber characteristic following 8 weeks of plyometric training. *The Journal Strength and Conditioning Research* **13,** 275-279.

Renfro, G. (1999) Summer plyometric training for football and its effect on speed and agility. *The Journal of Strength and Conditioning Research* **21,** 42-44.

Risberg, M.A., Holm, I., Steen, H., Eriksson, J. and Ekeland, A. (1999) The effect of knee bracing after anterior cruciate ligament reconstruction: a prospective randomized study with two years' follow-up. *The American Journal of Sports Medicine* **27,** 76-83.

Robinson, B.M. and Owen, B. (2004) Five-week program to increase agility, speed, and power in the preparation phase of a yearly training plan. *Strength Condionning* **26,** 30-35.

Rochcongar P. (2004) Evaluation isocinétique des extenseurs et fléchisseurs du genou en medecine du sport: revue de la littérature. *Annales de Réadaptation et de Médecine Physique* **47,** 274-281. (In French).

Sapega, A.A. (1990) Muscle performance evaluation in orthopaedic practice. *Journal Bone Joint Surgery American* **72,** 1562-1574.

Slemenda, C., Brandt, K.D., Heilman, D.K., Mazzuca, S., Braunstein, E.M., Katz, B.P. and Wolinsky, F.D. (1997) Quadriceps weakness and osteoarthritis of the knee. *Annals of Internal Medicine* **127(2),** 97-104.

Sporis, G., Jukic, I., Milanovic, L. and Vucetic, V. (2010) Reliability and factorial validity of agility tests for soccer players. *The Journal of Strength and Conditioning Research* **24,** 679-686.

Swanick, C.B. and Swanick, K.A. (1999) Plyometrics in rehabilitating the lower extremity. *Athletic Therapy Today* **4,** 16-22.

Tegner, Y. and Lysholm, J. (1985) Rating systems in the evaluation of knee ligament injuries. *Clinical Orthopedics* **198,** 43-49.

Tegner, Y., Lysholm, J., Lysholm, M. and Gillquist, J. (1986) A performance test to monitor rehabilitation and evaluate anterior cruciate ligament injuries. *The American Journal of Sports Medicine* **14,** 156-159.

Toumi, H., Best, T.M., Martin, A., Guyer, F. and Poumarat, G. (2004) Effects of eccentric phase velocity of plyometric training on the vertical jump. *International Journal of Sports Medicine* **25,** 391-398.

Wilk, K.E., Romaniello, W.T., Soscia, S.M., Arrigo, C.A. and Andrews, J.R. (1994) The relationship between subjective knee scores, isokinetic testing, and functional testing in the ACL reconstructed knee. *Journal of Orthopaedic & Sports Physical Therapy* **2,** 60-73.

Wilk, K.E., Reinol, M.M. and Hooks, T.R. (2003) Recent advances in the rehabilitation of isolated and combined anterior cruciate ligament injuries. *Orthopedic Clinic of North America* **34,** 107-137.

Wilkerson G.B., Colston M.A., Short N.I., Neal K.L., Hoewischer P.E. and Pixley J.J. (2004) Neuromuscular changes in female collegiate athletes resulting from a plyometric jump training program. *Journal of Athletic Training* **39(1),** 17-23.

Williams, G.N., Chmielewski, T., Rudolph, K., Buchanan, T.S. and Snyder-Mackler L. (2001) Dynamic knee stability: current theory and implications for clinicians and scientists. *Journal of Orthopaedic & Sports Physical Therapy* **31,** 546-566.

Wilson, G.J., Newton, R.U., Murphy, A.J. and Humphries, B.J. (1993) The optimal training load for the development of dynamic athletic performance. *Medicine and Science in Sports and Exercise* **25,** 1279-1286.

Wrobble, R.R. and Moxley, D.R. (2001) The effect of winter sports participation on high school football players: strength, power, agility, and body composition. *The Journal of Strength and Conditioning Research* **15,** 132-135.

Young, W.B., McDowell, M.H. and Scarlett, B.J. (2001) Specificity of spring and agility training methods. *The Journal Strength and Conditioning Research* **15,** 315-319.

Zatterstrom, R., Friden, T., Lindstrand, A. and Moritz U. (1992) Muscle training in chronic anterior cruciate ligament insufficiency- a comparative study. Scandinavian Journal *Rehabilitation Medicine* **24,** 91-97.

Key points

- Functional training (plyometrics, neuromuscular, proprioceptive and agility exercises) in athletes during 4th to 6th months post-ACLR further improved functional outcomes, compared to a conventional rehabilitation program.
- The former program was more time-efficient compared to the latter one as indicated by the weekly training duration (4hrs/week vs. 6hrs/week).
- This study provides evidence of the functional training in knee rehabilitation and provides important information that is highly relevant to clinicians, physiotherapists, coaches and trainers who are in charge of the injured athletes during the later phase of the rehabilitation after ACLR.

AUTHORS BIOGRAPHY

Sabrine SOUISSI
Employment
PhD student working in the field of rehabilitation. Sport and Physical Education teacher.
Degrees
Master in Exercise Science
Research interests
Functional training after Injuries
E-mail: sabrinesss@yahoo.fr

Del P. WONG
Employment
Assistant professor, Department of Health and Physical Education, The Hong Kong Institute of Education, Hong Kong
Degrees
DPhil
Research interests
elite sport performance, football science, sport physiology
E-mail: delwong@alumni.cuhk.net

Alexandre DELLAL
Employment
Fitness coach and headchief of science and research in Olympique Lyonnais FC (Soccer)
Degrees
PhD
Research interests
Training in soccer, match-analysis, small-sided games, injury in soccer
E-mail: alexandredellal@gmail.com

Jean-Louis CROISIER
Employment
Professor and Head of the Department of Motricity Sciences (University of Liege, Belgium
Degrees
MD
Research interests
Isokinetic evaluation-Motricity sciences
E-mail: jlcroisier@ulg.ac.be

Zied ELLOUZE
Employment
Doctor specialist in Rehabilitation and Physical Medicine
Degrees
MD
Research interests
Rehabilitation and Functional Training after sport injuries
E-mail: zied.ellouze@aspetar.com

Karim CHAMARI
Employment
Doctor in Exercise Physiology
Head of the Research Lab `Sport Performance Optimisation` National Centre of Medicine and Science in Sport.
Active researcher in football and sport science.
Fitness coach in professional soccer clubs
Degrees
PhD
Research interests
Physiology of Soccer - Physical capacities evaluation – Training
E-mail: karimchamari@gmx.net

🖂 **Del P. Wong,**
Department of Health and Physical Education, The Hong Kong Institute of Education, Hong Kong.