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EXPLOITING THE POTENTIAL OF MENTAL IMAGERY IN THE REHABILITATION OF ATHLETES FOLLOWING ANTERIOR CRUCIATE LIGAMENT SURGERY: A PILOT STUDY

APROVECHANDO EL POTENCIAL DE LA IMAGINERÍA MENTAL EN LA REHABILITACIÓN DE DEPORTISTAS TRAS CIRUGÍA DEL LIGAMENTO CRUZADO ANTERIOR: UN ESTUDIO PILOTO

***Sofien Kasmi*[1], *Wissal Boughattas*[2], *Hela Znazen*[2], *Mohammed A. Aljahni*[3], *Aissa ibn Dhia*[4], *Najwa Moella*[4]**

[1] National Center for Medicine and Sports Sciences of Tunis, ISSEP Ksar Said, Laboratory "Optimization of Sports Performance" LR09SEP01, Túnez
[2] Physical Sport Sciences department, College of Sport Sciences and Physical Activity, Princess Nourah bint Abdulrahman University, Riyadh, Arabia Saudita
[3] College of Arts and Humanities, Jazan University, Arabia Saudita

[4] Higher Institute of Sport and Physical Education of Ksar Said, University of Mannouba, Mannouba, Túnez

Correspondence:
Wissal E. Boughattas, WABoughattas@pnu.edu.sa

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Abstract

This pilot study examined the potential benefits of integrating mental imagery (MI) techniques into rehabilitation for athletes recovering from anterior cruciate ligament (ACL) surgery. Ten athletes (Mean age = 21.0 ± 4.5 years) were randomly assigned to either an experimental group (*n* = 5; MI plus physical therapy) or a control group (*n* = 5; physical therapy only) for 12 weeks. Outcome measures included the Y-Balance Test, isokinetic strength assessments at 90°/s, 180°/s, and 240°/s, and the Kinesthetic and Visual Imagery Questionnaire (KVIQ). Mixed-design ANOVA revealed significant Side-by-Group interactions for Y-Balance composite scores (p = .007), hamstring-to-quadriceps peak torque ratios across all three angular velocities ($p \leq .003$), and time-to-peak-torque of both flexor and extensor muscle groups ($p \leq .006$). For the KVIQ, significant Time-by-Group interactions emerged for the visual subscales (upper-limbs: p = .030; lower-limbs: p = .026), whereas the kinesthetic subscales did not reach statistical significance despite comparable effect sizes (p = .10). This pilot study provides preliminary evidence that integrating MI techniques into ACL rehabilitation may enhance dynamic balance, strength and time-to-peak-torque ratios, and visual imagery abilities, with similar (non-significant) trends for kinesthetic imagery. However, given the small sample size (*n* = 10), these findings should be interpreted cautiously and confirmed through larger randomized controlled trials before clinical recommendations are made.

Keywords: Anterior cruciate ligament, mental imagery, rehabilitation, pilot study.

Resumen

Este estudio piloto examinó los posibles beneficios de integrar técnicas de imaginería mental (IM) en la rehabilitación de deportistas que se recuperan de una cirugía del ligamento cruzado anterior (LCA). Diez deportistas (edad media = 21.0 ± 4.5 años) fueron asignados aleatoriamente a un grupo experimental (*n* = 5; IM más fisioterapia) o a un grupo control (*n* = 5; solo fisioterapia) durante 12 semanas. Las medidas de resultado incluyeron el Y-Balance Test, evaluaciones de fuerza isocinética a 90°/s, 180°/s y 240°/s, y el Cuestionario de Imaginería Cinestésica y Visual (KVIQ). El ANOVA de diseño mixto reveló interacciones significativas Lado × Grupo en las puntuaciones compuestas del Y-Balance Test (p = .007), en los cocientes de pico de torque isquiotibiales-cuádriceps en las tres velocidades angulares ($p \leq .003$) y en el tiempo hasta el pico de torque tanto de los grupos musculares flexores como extensores ($p \leq .006$). En el KVIQ surgieron interacciones significativas Tiempo * Grupo en las subescalas visuales (miembros superiores: p = .030; miembros inferiores: p = .026), mientras que las subescalas cinestésicas no alcanzaron la significación estadística a pesar de presentar tamaños del efecto comparables (p = .10). Este estudio piloto aporta evidencia preliminar de que integrar técnicas de IM en la rehabilitación del LCA podría mejorar el equilibrio dinámico, la fuerza, los cocientes de tiempo hasta el pico de torque y las capacidades de imaginería visual, con tendencias similares (no significativas) para la imaginería cinestésica. No obstante, dado el reducido tamaño muestral (*n* = 10), estos resultados deben interpretarse con cautela y confirmarse mediante ensayos controlados aleatorizados de mayor tamaño antes de formular recomendaciones clínicas.

Palabras clave: Ligamento cruzado anterior, imaginería mental, rehabilitación, estudio piloto.

Introduction

High-level sports training requires a careful balance between pushing the limits of physical performance and managing the inherent risks of injury. Injuries are a common and challenging aspect of an athlete's career, often necessitating surgery and extensive rehabilitation (McVeigh & Pack, 2015). Daley et al. (2021) explained that injuries can be a source of psychological distress for athletes, potentially affecting the physical rehabilitation process. The authors also emphasized the importance of considering the psychological impact of injury and providing appropriate mental health support, making a holistic approach to rehabilitation essential for optimizing recovery outcomes.

Anterior cruciate ligament (ACL) tears, one of the most common lower limb sports injuries, are known for their lengthy recovery times, often requiring months of intensive rehabilitation before athletes can safely return to sport (Malempati et al., 2015). This prolonged absence from training and competition can significantly affect an athlete's mental well-being, leading to frustration, anxiety, and self-doubt (Plakoutsis et al., 2022). To optimize rehabilitation and facilitate a successful return to sport, it is crucial to address both the physical and psychological aspects of recovery. Several studies have highlighted the importance of addressing psychological factors during ACL rehabilitation. Beischer et al. (2019) found that psychological readiness was strongly associated with knee function and return to sport among adolescent athletes 12 months postsurgery. Similarly, Coronado et al. (2018) conducted a systematic review and found limited evidence suggesting that psychosocial interventions may enhance patient-reported outcomes and reduce fear of reinjury, although higher-quality research is needed.

Moreover, while traditional rehabilitation protocols primarily emphasize physical therapy and strength training, there is growing recognition of the value of incorporating mental training techniques, such as mental imagery (MI), to enhance recovery outcomes and improve athletes' psychological readiness to return to competition (Cupal & Brewer, 2001; Lebon et al., 2012). MI is a cognitive process in which individuals visualize themselves performing an action without actual physical movement. Numerous studies suggest that MI, when combined with traditional physiotherapy, may contribute to improved clinical outcomes, reduced knee laxity, enhanced neurobiological function, muscular recovery, and greater psychological well-being following ACL surgery (Maddison et al., 2012; Pastora-Bernal et al., 2021; Rodríguez et al., 2019). However, the effectiveness of MI interventions has produced mixed results. Some studies report positive effects on pain, anxiety, fear of reinjury, functional performance, and activities of daily living, whereas others have not found conclusive evidence of such benefits (Pastora-Bernal et al., 2021).

The use of MI in ACL rehabilitation can further be strengthened by integrating it into a comprehensive rehabilitative approach. A study of elite athletes who underwent comprehensive rehabilitation found that a greater proportion returned to preinjury activity levels, and a lower percentage experienced re-rupture compared with previous studies (Takahashi et al., 2023). Additionally, psychological support can be provided through self-directed interventions, such as the Back in the Game application, which has demonstrated positive user experiences among athletes during rehabilitation following ACL reconstruction (Ringberg et al., 2023). Furthermore, Cederström et al. (2021) found that incorporating MI into knee injury prevention and rehabilitation training significantly increased enjoyment compared to traditional training alone, suggesting that MI may serve as a valuable tool to enhance adherence and motivation.

While the evidence regarding the effectiveness of MI in ACL rehabilitation remains mixed, existing research suggests potential benefits, particularly in relation to psychological factors and specific physical outcomes. A multidisciplinary approach that integrates psychological interventions may enhance the rehabilitation process and increase the likelihood of a successful return to sport. However, the application of MI techniques in sport rehabilitation, specifically for ACL injuries, remains relatively understudied in existing literature. In this context, the present study provides a rigorous investigation of MI techniques as a complementary therapy to traditional rehabilitation protocols for ACL injuries.

The aim of this pilot study was to examine the potential benefits of incorporating MI techniques into the rehabilitation protocol for athletes recovering from ACL surgery, with the goal of developing a more comprehensive and effective approach to ACL rehabilitation. It was hypothesized that integrating MI techniques would lead to improved outcomes in dynamic balance, strength ratios, and motor imagery abilities compared with traditional physical therapy alone. Given the exploratory nature of the study and the limited sample size, this investigation was designed as a pilot study to assess the feasibility of the intervention and provide preliminary effect size estimates for future adequately powered trials.

Materials and Methods

Study Design

This pilot study employed a randomized controlled trial (RCT) design to examine the effectiveness of MI in the rehabilitation of athletes following anterior cruciate ligament (ACL) surgery. The study was conducted between January 2023 and June 2023 in the National Center of Medicine and Science in Sports (CNMSS), Tunis, Tunisia. The study period included a 12-week intervention with assessments conducted before and after the intervention.

Participants

This pilot study initially enrolled 10 athletes who had undergone ACL reconstruction surgery. The sample size was determined based on feasibility considerations typical of pilot studies designed to assess intervention practicality and provide preliminary effect size estimates for future adequately powered trials. Inclusion criteria were as follows: (1) ACL reconstruction surgery performed within 6-8 weeks prior to enrollment; (2) medical clearance to participate in rehabilitation; (3) participation in competitive sports before the injury; and (4) no prior involvement in formal mental training programs. Exclusion criteria included (1) previous ACL surgery on either knee; (2) concurrent lower-limb injuries; (3) neurological or psychological conditions that could interfere with imagery ability; and (4) inability to attend twice-weekly sessions. Participants were randomly assigned to either the experimental group (EXG, $n = 5$) or the control group (CG, $n = 5$). Allocation was performed by an independent researcher who was not involved in participant recruitment or assessment. Outcome assessors were blinded to group allocation. Due to the nature of the intervention, participants and therapists could not be blinded to group assignment. The same examiner conducted all preintervention and postintervention assessments for each outcome measure to ensure consistency. All participants provided informed written consent before enrollment.

Procedures

At baseline, all participants completed the Kinesthetic and Visual Imagery Questionnaire (KVIQ); the KVIQ was repeated after the 12-week intervention to evaluate pre-post changes in motor imagery ability. The Y-Balance Test and isokinetic strength assessments were conducted at the end of the 12-week intervention, comparing the operated and non-operated knees within each participant. Both groups participated in standardized physical therapy sessions twice weekly for 12 weeks. All sessions were conducted by qualified physiotherapists with experience in post-ACL reconstruction rehabilitation. The experimental group received an additional MI intervention lasting 15–20 minutes immediately before each physical therapy session. The control group received physical therapy only, with equivalent total contact time maintained through additional warm-up activities.

Physical Therapy Protocol (Both Groups)

All participants followed a standardized physical therapy program based on established ACL reconstruction rehabilitation protocols (Kasmi et al., 2021; Kasmi et al., 2023; Wilk & Arrigo, 2016). The program was administered twice weekly for 12 weeks and comprised five progressive phases: Phase 1 (weeks 1–2): pain and swelling control, restoration of range of motion (ROM; 0–90°), and quadriceps activation. Phase 2 (weeks 3-4): achievement of full ROM, progressive weight bearing, and proprioception training on stable surfaces. Phase 3 (weeks 5–8): closed kinetic chain strengthening, balance training on unstable surfaces, and cycling with resistance. Phase 4 (weeks 9–10): advanced strengthening, agility drills, progressive plyometric exercises, and sport-specific movements. Phase 5 (weeks 11–12): sport-specific drills, cutting and pivoting exercises, and high-intensity plyometric training.

Each phase included exercises targeting range of motion, strengthening, proprioception, and neuromuscular control. Progression between phases was individualized based on specific criteria, including ROM, strength deficits, and functional performance. Each session lasted approximately 60 minutes and was supervised by qualified physiotherapists. Detailed protocol specifications are provided in supplementary materials.

Mental Imagery Protocol

The experimental group received additional MI training based on the PETTLEP model (Holmes & Collins, 2001) for 15–20 minutes immediately before each physical therapy session. The PETTLEP model incorporates seven elements designed to enhance imagery effectiveness: Participants wore sports clothing and adopted positions that matched the imagined movements (e.g., standing when visualizing weight-bearing exercises). Environment: Imagery sessions were conducted in the rehabilitation gym where physical therapy took place to maximize contextual similarity. Task: Participants imagined specific exercises from their current rehabilitation phase, focusing on accurate movement sequences and associated body sensations. Timing: Imagery was performed in real time to match the pace of actual exercise execution. Learning: Imagery content increased in complexity to correspond with participants' progression through rehabilitation phases. Emotion: Participants focused on positive emotions, confidence, and successful completion of movement. Perspective: An internal (first-person) perspective was emphasized to enhance kinesthetic sensations.

Each session was guided by a trained researcher using standardized scripts. Participants visualized three to five key exercises from their upcoming physical therapy session, completing two to three repetitions of each imagery sequence. Sessions began with relaxation techniques (e.g., deep breathing for 2–3 minutes), followed by progressive imagery practice.

Measures

Kinesthetic and Visual Imagery Questionnaire (KVIQ)

The KVIQ-20 (Malouin et al., 2007) was used to assess participants' mental imagery ability. This questionnaire consists of 20 items (10 assessing visual imagery and 10 assessing kinesthetic imagery) representing simple movements of the head, shoulders, trunk, upper limbs, and lower limbs. All movements are performed in a seated position, making the assessment suitable for individuals with physical limitations. For each item, participants first physically performed the movement and then imagined performing it. They rated either the clarity of the visual image (visual subscale) or the intensity of kinesthetic sensations (kinesthetic subscale) on a 5-point scale ranging from 1 (no image/sensation) to 5 (image as clear as seeing/ sensation as intense as executing the movement). The KVIQ-20 was administered by a trained examiner who read the instructions aloud and recorded the participants' responses. Total scores range from 10-50 for each subscale, with higher scores indicating greater imagery ability.

Y-Balance Test

The Y-Balance Test (YBT) is a dynamic balance assessment in which participants maintain a single-leg stance while reaching as far as possible with the contralateral leg in three directions: anterior, posteromedial, and posterolateral (Figure 1). Participants stood barefoot on the test platform, with the most distal aspect of the great toe positioned at the center of the grid. While maintaining a single-leg stance on the test leg, participants pushed a reach indicator with the contralateral great toe as far as possible in each direction without losing balance. The heel of the stance leg was required to remain in contact with the platform throughout the reach. After reaching maximal distance, participants returned the reaching foot to the starting position in a controlled manner. Trials were discarded if participants (1) failed to maintain a unilateral stance, (2) did not return the reaching foot to the starting position under control, or (3) used the reaching foot for support. Following six practice trials (two in each direction), participants completed three test trials per direction with 30 second rest intervals between trials. Maximal reach distances were recorded to the nearest 0.5 cm. The Y-Balance composite score (YBT-CS) was calculated using the following formula: YBT-CS = (anterior reach + posteromedial reach + posterolateral reach) / (3 × limb length) × 100. Limb length was measured from the anterior superior iliac spine to the medial malleolus. Testing was conducted on both the operated and non-operated limbs.

Figure 1

Y-Balance Test Procedure Demonstrating the Three Reach Directions (Anterior, Posteromedial, and Posterolateral)

Isokinetic Strength Assessment

Isokinetic muscle strength was assessed using an isokinetic dynamometer. Participants were seated with the hip flexed at 90°, and the dynamometer axis was aligned with the lateral femoral epicondyle. Stabilization straps were applied across the chest, pelvis, and thigh, and the resistance pad was positioned 3 cm proximally to the medial malleolus. Following a standardized warm-up consisting of 5 minutes of stationary cycling and 10 submaximal knee flexion-extension repetitions, participants performed concentric isokinetic testing of knee flexors and extensors at three angular velocities: 90°/s: five maximal repetitions; 180°/s: five maximal repetitions; 240°/s: 20 maximal repetitions. Two-minute rest intervals were provided between each velocity. The range of motion was set from 0° (full extension) to 90° (flexion). Participants received standardized verbal encouragement throughout testing. Outcome measures included (1) peak torque (Nm) for flexors and extensors, (2) peak torque ratios (flexor/extensor), and (3) accelerated time to peak torque (seconds). Testing was conducted on both the operated and non-operated limbs. All assessments were performed by a qualified physiotherapist experienced in isokinetic testing.

Statistical Analysis

Data are presented as mean ± standard deviation. Baseline characteristics were compared between groups using independent t-tests (continuous) and Fisher's exact test (categorical). A two-way mixed ANOVA was conducted for each outcome, with Group (EXG, CG) as the between-subjects factor and Side (operated, non-operated) as the within-subjects factor for functional and isokinetic outcomes, or Time (pre, post) for the KVIQ. The Side-by-Group (or Time-by-Group, for KVIQ) interaction was the primary outcome. Effect sizes were reported as Cohen's d for paired contrasts (Cohen, 1988) and partial eta-squared (η^2p) for ANOVA, with conventional thresholds for small, medium, and large effects. To address potential confounding from baseline anthropometric variability, an ANCOVA was performed for each outcome with the side deficit or KVIQ change score as the dependent variable, Group as the between-subjects factor, and BMI as a covariate. Analyses were performed using SPSS Statistics 27.0 (IBM Corp., Armonk, NY). Given the pilot design (n = 10), results emphasize effect sizes over statistical significance.

Results

Demographic and Clinical Characteristics

Baseline characteristics are presented in Table 1. The experimental (EXG) and control (CG) groups were comparable across all measured characteristics: age (21.2 ± 4.7 vs. 20.8 ± 4.4 years, p = .893), sex distribution (three males/two females each, p = 1.000), sport experience (7.8 ± 3.3 vs. 9.6 ± 1.1 years, p = .288), and body mass index (BMI; 22.39 ± 1.85 vs. 24.49 ± 2.59

kg/m², $p = .177$). Although the CG showed a numerically higher mean BMI (~2 kg/m² difference), the difference did not reach statistical significance. Time since surgery ranged from 13 to 21 weeks across both groups. Participants represented a variety of contact and combat sports, with football most common in the EXG ($n = 2$) and handball most common in the CG ($n = 2$).

Table 1

Demographic and Clinical Characteristics

Characteristic	EXG (n = 5)	CG (n = 5)	p-value
Age (years)	21.2 ± 4.7	20.8 ± 4.4	.893
Body Mass Index (kg/m²)	22.39 ± 1.85	24.49 ± 2.59	.177
Sex (Male/Female)	3 / 2	3 / 2	1.000
Sport experience (years)	7.8 ± 3.3	9.6 ± 1.1	.288
Time since surgery (weeks)	13-21	13-21	-
Sport participation			
Football	2	1	
Handball	1	2	
Judo	1	0	
Jiu-jitsu	1	0	
Other (Boxing, Karate)	0	2	

Note. Values are mean ± SD unless otherwise indicated. EXG = experimental group; CG = control group. No significant baseline differences were found (all $p > .05$).

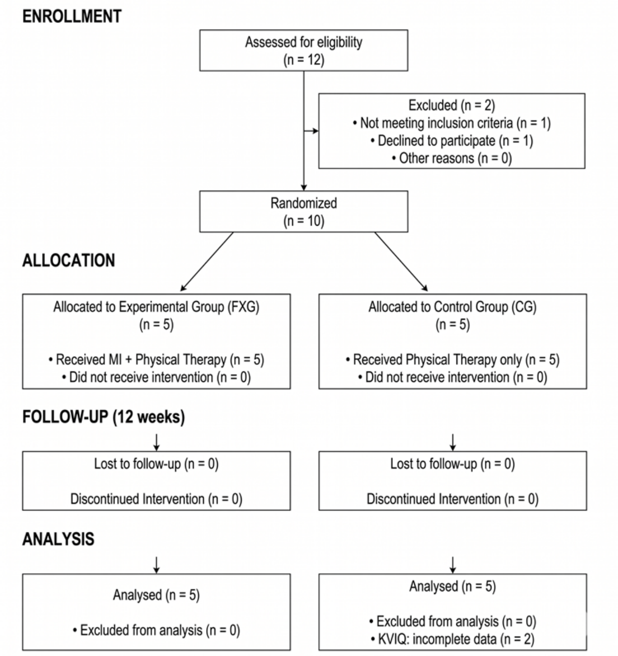
Participant Flow

Figure 2 presents the CONSORT flow diagram for this pilot study. Twelve athletes who had undergone ACL reconstruction surgery were assessed for eligibility between January and June 2023. Two athletes were excluded: one did not meet the inclusion criteria (concurrent lower-limb injury), and one declined to participate due to scheduling conflicts. The remaining ten athletes were enrolled and randomly allocated to either the experimental group (EXG, $n = 5$; mental imagery plus physical therapy) or the control group (CG, $n = 5$; physical therapy only) using computer-generated random numbers with sealed opaque envelopes.

All ten participants completed the full 12-week intervention protocol. No participants were lost to follow-up, discontinued the intervention, or withdrew from the study. Adherence to the intervention was 100% in both groups. All participants were included in the primary analysis. For the KVIQ assessment, incomplete data were obtained for two participants in the control group; these cases are noted in the relevant analyses.

Figure 2

CONSORT Flow Diagram



Y-Balance Test Performance

Y-Balance Test composite scores revealed contrasting patterns between groups (Table 2). The experimental group demonstrated near-symmetrical performance between the non-operated (99.64 ± 3.77%) and operated knees (99.68 ± 3.86%), resulting in a minimal deficit of 0.04 ± 2.21% (*d* = 0.01). In contrast, the control group exhibited marked asymmetry, with the non-operated knee scoring substantially higher (105.22 ± 8.28%) than the operated knee (99.06 ± 8.34%), producing a deficit of -6.16 ± 3.12% (*d* = -1.74).

Table 2

Y-Balance Test Performance: Operated vs. Non-Operated Limb Comparison

Group	Non-operated knee	Operated knee	Deficit	Cohen's d	SWC Likelihood (%) Higher/Trivial/ Detrimental
EXG	99.64 ± 3.77	99.68 ± 3.86	0.04 ± 2.21	0.01	51.1 / 23.4 / 15.5
CG	105.22 ± 8.28	99.06 ± 8.34	-6.16 ± 3.12	-1.74	1.3 / 0.2 / 98.4

Note. Mean ± SD. Deficit = (non-operated − operated knee); negative values indicate lower performance in the operated limb.

Isokinetic Strength Assessment

Peak Torque Ratios

Significant Side × Group interactions were observed for hamstring-to-quadriceps peak torque ratios at all three velocities (Force $F(1,8) = 31.93$, $p < .001$, $\eta^2p = .80$; Power $F(1,8) = 18.67$, $p = .003$, $\eta^2p = .70$; Endurance $F(1,8) = 135.53$, $p < .001$, $\eta^2p = .94$) (Table 3). At 90°/s, the experimental group exhibited lower ratios in the operated knee (59.18 ± 7.37% vs. 68.34 ± 4.50%, *d* = -2.03), whereas the control group displayed substantially higher ratios in the operated limb (81.46 ± 15.42% vs. 61.34 ± 7.49%, *d* = 2.69). Similar patterns emerged at 180°/s (EXG: 61.48 ± 7.61% vs. 70.58 ± 8.59%, *d* = -1.06; CG: 88.34 ± 19.50% vs. 66.98 ± 7.34%, *d* = 2.91).

Table 3

Peak Torque Ratios (Concentric Flexor/Extensor): Comparison Between Operated and Non-Operated Knees

Velocity	**Group**	**Non-operated knee (%)**	**Operated knee (%)**	**Deficit**	**Cohen's d**	**SWC Likelihood (%) Higher/ Trivial/ Detrimental**
90°/s	EXG	68.34 ± 4.50	59.18 ± 7.37	-9.16 ± 4.24	-2.03	0.3/0.3/99.6
	CG	61.34 ± 7.49	81.46 ± 15.42	20.12 ± 10.78	2.69	0.4/0.5/99.1
180°/s	EXG	70.58 ± 8.59	61.48 ± 7.61	-9.10 ± 6.85	-1.06	2.5/1.2/96.3
	CG	66.98 ± 7.34	88.34 ± 19.50	21.36 ± 14.20	2.91	0.6/1.1/98.2
240°/s	EXG	84.64 ± 5.62	100.60 ± 7.25	15.96 ± 3.48	2.84	100/0/0
	CG	87.52 ± 7.50	78.68 ± 9.23	-8.84 ± 3.26	-1.18	0.3/0/99.6

Note. Mean ± *SD*. Deficit = (operated − non-operated knee).

At 240°/s, the directional pattern reversed for the experimental group, with the operated knee demonstrating markedly higher ratios (100.60 ± 7.25% vs. 84.64 ± 5.62%, $d = 2.84$). Conversely, the control group maintained lower ratios in the operated limb (78.68 ± 9.23% vs. 87.52 ± 7.50%, $d = -1.18$).

Time to Peak Torque

For concentric knee flexors (Table 4), significant Side × Group interactions emerged at all three velocities (Force $F(1,8) = 34.29$, $p < .001$, $\eta^2p = .81$; Power $F(1,8) = 15.89$, $p = .004$, $\eta^2p = .67$; Endurance $F(1,8) = 27.86$, $p = .001$, $\eta^2p = .78$). The experimental group achieved peak torque more rapidly in the operated knee at all velocities (90°/s: $d = -1.08$; 180°/s: $d = -1.13$; 240°/s: $d = -0.89$), whereas the control group demonstrated slower attainment in the operated limb (90°/s: $d = 0.69$; 180°/s: $d = 1.00$; 240°/s: $d = 2.52$).

Table 4

Accelerated Time to Peak Torque for Concentric Flexors: Comparison Between Operated and Non-Operated Knees

Velocity	**Group**	**Non-operated knee (s)**	**Operated knee (s)**	**Deficit (s)**	**Cohen's d**	**SWC Likelihood (%) Higher/ Trivial/ Detrimental**
90°/s	EXG	0.05 ± 0.02	0.03 ± 0.02	-0.02 ± 0.01	-1.08	0.3/0.7/99.0
90°/s	CG	0.02 ± 0.02	0.03 ± 0.02	0.01 ± 0.01	0.69	96.7/2.8/0.5
180°/s	EXG	0.08 ± 0.02	0.06 ± 0.02	-0.02 ± 0.02	-1.13	1.6/2.7/95.7
180°/s	CG	0.06 ± 0.02	0.08 ± 0.01	-0.02 ± 0.01	1.00	96.0/2.7/1.2
240°/s	EXG	0.12 ± 0.03	0.09 ± 0.02	-0.03 ± 0.02	-0.89	1.1/2.9/96.0
240°/s	CG	0.09 ± 0.01	0.11 ± 0.01	0.03 ± 0.01	2.52	99.8/0.1/0.1

Note. Mean ± *SD*. Negative deficit = faster time to peak torque in operated limb.

Similarly, for concentric knee extensors (Table 5), the experimental group reached peak torque faster in the operated knee at all velocities (90°/s: $d = -0.81$; 180°/s: $d = -1.83$; 240°/s: $d = -1.33$), whereas the control group exhibited slower times in the operated limb (90°/s: $d = 1.83$; 180°/s: $d = 1.49$; 240°/s: $d = 0.71$).

Table 5

Comparison Between Operated and Non-Operated Knees Based on Accelerated Time to Peak Torque for Concentric Extensors

Velocity	Group	Non-operated knee (s)	Operated knee (s)	Deficit (s)	Cohen's d	SWC Likelihood (%) Higher/ Trivial/ Detrimental
90°/s	EXG	0.04 ± 0.02	0.02 ± 0.01	-0.01 ± 0.01	-0.81	0.1/0.6/99.3
	CG	0.01 ± 0.01	0.02 ± 0.01	0.01 ± 0.00	1.83	99.4/0.3/0.3
180°/s	EXG	0.07 ± 0.01	0.05 ± 0.01	-0.01 ± 0.00	-1.83	0.0/0.1/99.9
	CG	0.05 ± 0.01	0.07 ± 0.01	0.01 ± 0.01	1.49	99.0/0.6/0.4
240°/s	EXG	0.11 ± 0.02	0.08 ± 0.00	-0.03 ± 0.02	-1.33	1.6/2.1/96.3
	CG	0.08 ± 0.01	0.09 ± 0.01	0.01 ± 0.01	0.71	97.9/1.8/0.3

Note. Mean ± SD.

Kinesthetic and Visual Imagery Questionnaire

Pre-post changes in motor imagery ability are presented in Table 6. The 2 × 2 mixed ANOVA revealed significant Time-by-Group interactions for the visual subscales (visual upper-limbs $F(1,8) = 6.97$, $p = .030$, $\eta^2p = .47$; visual lower-limbs $F(1,8) = 7.45$, $p = .026$, $\eta^2p = .48$), with the experimental group showing improvements while the control group's performance declined or remained stable. For the kinesthetic subscales, the within-group Cohen's d values for the experimental group were also large ($d = 0.95$ for both upper and lower limbs), but the Time-by-Group interactions did not reach statistical significance (kinesthetic upper-limbs $F(1,8) = 3.46$, $p = .100$, $\eta^2p = .30$; kinesthetic lower-limbs $F(1,8) = 3.37$, $p = .104$, $\eta^2p = .30$), likely reflecting limited statistical power at this sample size rather than absence of an effect.

Table 6

Kinesthetic and Visual Imagery Questionnaire (KVIQ) Scores

		Visual Imagery				**η^2p**	**Kinesthetic Imagery**				**η^2p**
Body Region	*Group*	*Pre*	*Post*	*Cohen's d*	*SWC (%) H/T/D*	(*Time × Group*)	*Pre*	*Post*	*Cohen's d*	*SWC (%) H/T/D*	(*Time × Group*)
Upper Limbs	EXG	30.40 ± 8.02	38.60 ± 3.71	1.02	0.6/1.5 / 97.4	.47*	30.60 ± 8.20	38.40 ± 3.78	0.95	1.9/3.9 /94.2	.30
	CG	34.00 ± 7.18	28.00 ± 5.52	-0.84	79.8/10.0 /10.1		20.00 ± 8.72	21.20 ± 7.33	0.14	8.6/52.7 /38.7	
Lower Limbs	EXG	28.00 ± 10.56	36.20 ± 3.96	0.78	1.5/4.7 /93.8	.48*	27.60 ± 8.56	36.40 ± 3.78	0.95	2.4/5.7 /91.9	.30
	CG	25.33 ± 11.50	25.67 ± 6.03	0.03	11.9/65.2 /22.9		20.00 ± 7.65	21.40 ± 5.94	0.18	6.2/47.1 /46.8	

Note. Mean ± *SD*. EXG = experimental group; CG = control group. Cohen's d = within-group pre-post change. η^2p = partial eta-squared from the Time-by-Group interaction (2 × 2 mixed ANOVA), applies to both groups jointly. *$p < .05$ (significant interaction). SWC = smallest worthwhile change likelihood (Higher / Trivial / Detrimental, %).

Discussion

This pilot study examined the integration of PETTLEP-based mental imagery (MI) training into standard physical therapy for athletes recovering from ACL reconstruction. Despite the small sample size, which warrants cautious interpretation, the findings suggest potential benefits across dynamic balance, neuromuscular function, and visual motor imagery ability. Improvements in kinesthetic imagery were also large in magnitude but did not reach statistical significance, likely owing to limited statistical power at this sample size.

The Y-Balance Test revealed a notable pattern: the experimental group maintained near-symmetrical performance between limbs (0.04% deficit), whereas the control group exhibited a 6.16% deficit, corresponding to a large effect size (Cohen's $d = 1.74$). These results suggest that MI may promote more balanced neuromuscular recovery, aligning with previous evidence indicating that imagery can enhance functional outcomes following ACL reconstruction (Maddison et al., 2012). Mechanistically, these improvements may stem from enhanced motor planning and preparatory neural activation, as MI has been shown to engage cortical regions overlapping with those involved in actual movement execution.

Isokinetic strength assessments revealed velocity-dependent effects. Significant Side × Group interactions emerged for the hamstring-to-quadriceps peak torque ratios at all three velocities (η^2p = .70 to .94), as well as for the time to peak torque of both flexors (η^2p = .67 to .81; all $p \leq .004$) and extensors (η^2p = .63 to .87; all $p \leq .006$) across all three velocities. The experimental group consistently demonstrated faster time to peak torque in the operated limb, while the control group exhibited slower activation patterns. These findings imply that MI may differentially influence muscle recruitment, depending on contraction speed, potentially through improved neural drive and reduced cortical inhibition (Grosprêtre et al., 2019; Rozand et al., 2019). Neurophysiological research supports this interpretation, showing that MI activates motor pathways similar to those required during actual movement, including the primary motor cortex and supplementary motor areas (Hardwick et al., 2018; Mizuguchi et al., 2023).

Findings from the KVIQ assessments showed a modality-specific pattern. The experimental group demonstrated substantial within-group improvements across both visual and kinesthetic subscales (d = 0.78 to 1.02), whereas the control group showed minimal or declining performance. The Time × Group interactions reached statistical significance for the visual subscales (visual upper-limbs η^2p = .47, p = .030; visual lower-limbs η^2p = .48, p = .026) but did not reach significance for the kinesthetic subscales (η^2p = .30 for both, p = .10), although the kinesthetic effect sizes were also large. The non-significance of the kinesthetic interactions likely reflects limited statistical power at this sample size rather than absence of an effect. These divergent trajectories provide strong preliminary evidence that structured imagery training enhances athletes' capacity to generate vivid and accurate movement representations. Enhanced MI ability has practical implications, as it is closely linked to motor learning efficiency, neuromuscular control, and psychological readiness for return to sport (Beischer et al., 2019). By strengthening the cognitive-motor connection, mental imagery may simultaneously support both physical and psychological dimensions of recovery.

These findings add to growing evidence supporting multidisciplinary rehabilitation approaches (Coronado et al., 2018; Pastora-Bernal et al., 2021). While conventional ACL protocols effectively restore physical function, addressing psychological factors may optimize outcomes for athletes at risk of failing to return to preinjury performance levels. The present results align with Coronado et al. (2018) systematic review, which suggests potential benefits of psychosocial interventions. The PETTLEP framework's emphasis on functional equivalence, through physical positioning, environmental context, and emotional engagement, may explain the consistent positive effects observed. Furthermore, Cederström et al. (2021) demonstrated that incorporating motor imagery significantly enhanced rehabilitation enjoyment, an outcome with important implications for adherence during lengthy postsurgical recovery periods.

Limitations

This pilot study has several notable limitations. The small sample (n = 10) severely constrains statistical power and generalizability, yielding effect-size estimates that are inherently imprecise at this sample size and may shift substantially when tested in larger samples. Conducting the study at a single center with a relatively homogeneous group of athletes further limits the applicability of these findings to broader and more diverse populations.

Although the experimental and control groups did not differ significantly at baseline in BMI (22.39 ± 1.85 vs. 24.49 ± 2.59 kg/m², p = .177), the magnitude of the numerical difference (~2 kg/m²) warranted a sensitivity analysis. ANCOVAs were therefore performed on each outcome with the side deficit (operated−non-operated knee) or KVIQ change score as the dependent variable and the individual BMI as a covariate. For the functional and isokinetic outcomes, the BMI-adjusted Group effects remained large and statistically significant for Y-Balance (F(1,7) = 9.52, p = .018, η^2p = .58), the three peak torque ratios (Force F(1,7) = 24.46, p = .002, η^2p = .78; Power F(1,7) = 15.73, p = .005, η^2p = .69; Endurance F(1,7) = 136.46, p < .001, η^2p = .95), and the time-to-peak-torque outcomes for both flexors (η^2p = .77 to .83; all $p \leq .015$) and extensors (η^2p = .68 to .87; all $p \leq .006$) at all three velocities. For the KVIQ subscales, the BMI-adjusted Group effects were significant for visual lower-limbs (F(1,7) = 11.13, p = .012, η^2p = .61) and visual upper-limbs (F(1,7) = 5.67, p = .049, η^2p = .45), and approached significance for kinesthetic lower-limbs (F(1,7) = 5.19, p = .057, η^2p = .43) and kinesthetic upper-limbs (F(1,7) = 4.09, p = .083, η^2p = .37). The BMI covariate itself was not a significant predictor in any of the fourteen models (all p > .057), indicating that BMI did not substantially confound the observed between-group differences. The pattern of conclusions is therefore consistent with the unadjusted ANOVAs.

Additionally, the absence of long-term follow-up prevents assessment of whether the observed benefits persisted over time or facilitated a successful return to sport. Future research should include follow-up assessments at six months, one year, and beyond to evaluate the durability of intervention effects and their influence on functional performance outcomes.

Future Directions

This pilot study identifies several critical directions for future research. A fully powered randomized controlled trial is essential to validate these preliminary findings, incorporating multiple post-intervention assessments and tracking participants through return-to-sport and at least one year post-rehabilitation to capture reinjury rates. Future investigations should also examine dose-response relationships and determine the optimal timing for introducing MI, as its benefits may differ between early postoperative and later rehabilitation phases. Moreover, exploring the underlying neural mechanisms could help identify which athletes are most likely to benefit from imagery-based interventions. Individual factors, such as imagery ability, motivation, and psychological readiness, may also moderate effectiveness and should be considered when designing tailored rehabilitation programs.

Conclusion

This pilot study provides preliminary evidence examining the effect of PETTLEP-based mental imagery combined with ACL rehabilitation, suggesting it may enhance dynamic balance and visual motor imagery capacity (with non-significant trends in the same direction for kinesthetic imagery) in injured athletes. The observed effect sizes indicate clinically meaningful benefits beyond physical therapy alone, highlighting the importance of addressing cognitive and psychological dimensions in recovery. However, the small sample size necessitates cautious interpretation. Moreover, heterogeneity in some measures suggests that mental imagery may influence motor function through mechanisms that require further investigation. If replicated in larger trials, mental imagery could become a standard component of evidence-based ACL rehabilitation. Future research should prioritize adequately powered studies with long-term follow-up to determine whether these effects translate into sustained functional benefits and reduce reinjury risk.

Ethics Committee Statement

This study was conducted as an exploratory pilot investigation to assess the feasibility and preliminary outcomes of mental imagery interventions in post-ACL surgery rehabilitation. Given the exploratory and preliminary nature of this work, formal ethical committee approval was not obtained prior to data collection. However, all procedures were conducted in accordance with the ethical standards of the Declaration of Helsinki and institutional guidelines for clinical practice evaluation.

All participants provided informed written consent before participating in the imagery intervention program. Participants were informed that their anonymized rehabilitation data might be used for clinical practice improvement and research purposes. No experimental procedures beyond standard rehabilitation protocols were implemented, and all interventions were consistent with evidence-based clinical practice.

Data were collected retrospectively from clinical records and anonymized prior to analysis to ensure participant confidentiality. No personally identifiable information was retained in the dataset. Participants' rights to privacy and confidentiality were strictly maintained throughout the study.

The findings of this pilot study are presented as preliminary exploratory results intended to generate hypotheses and inform the design of future confirmatory research with prospective ethical approval.

Conflict of Interest

The authors declare no conflicts of interest with any financial organization regarding the material discussed in this manuscript.

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Authors' Contributions

SK and WB conceived and designed the study. HZ, NM and MAA conducted the literature review. AID, SK and NM collected the data. WB analyzed the data. HZ and WB drafted the manuscript. All authors critically revised the manuscript for important intellectual content and approved the final version.

Data Availability Statement

Data available upon request to the corresponding author WABoughattas@pnu.edu.sa

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