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The Effect of Core Stability Training on Improving Lower Limb Muscle Stability and Flexibility During Knee Injury Recovery

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Abstract

Study purpose. The purpose of this study is to determine the effect of Core Stability Training (CST) on improving leg muscle stabilization and flexibility in the recovery of knee injuries among athletes.

Materials and methods. The participants of this study consisted of 18 male athletes from 4 sports (badminton, running, football, basketball) in Bandung with ACL/PCL knee injuries (injury age: 6 months), divided into 2 groups via random assignment, using true experimental with pre-test post-test control group design with 12 sessions of CST for the experimental group versus control training for the control group. The treatment was conducted over 12 sessions. Data collection was carried out by administering a pre-test and post-test using the single leg squat test to measure leg muscle stabilization and a goniometer to measure knee joint range of motion (ROM). Data were analyzed using the t-test for normally distributed data (ROM) and the non-parametric Wilcoxon test for non-normally distributed data (single leg squat), with normality tested using the Saphiro-Wilk test. Statistical significance was set as $p < 0.05$.

Results. For leg muscle stabilization, CST group improved by 97.22% vs. control group by 46.67% ($p=0.000$), indicating a significant difference between group, and for flexibility, CST group improved by 36.22% (from 81.11° to 127.11° vs. control group by 27.37% (from 82.22° to 113.11°) ($p=0.000$), indicating a significant difference between groups.

Conclusions. The Core Stability Training method has a significant effect on improving leg muscle stabilization and knee joint flexibility during the recovery of a knee injury.

Keywords: Core stability training, Flexibility, Knee injuries, Recovery, Stability.

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Introduction

The most common injury experienced by athletes is a knee injury. This injury can be caused by various factors, including poor technique, wearing the wrong shoes, and failing to warm up before exercising. Athletes who participate in sports involving knee-bending movements, such as soccer, basketball, and running, are more prone to knee injuries (Pristianto & Sudawan, 2021). Based on sport type, knee injuries among athletes in Bangladesh are predominantly seen in soccer (30%), basketball (25%), running (20%), cricket (15%), and other sports (10%). The most common knee injury is an anterior cruciate ligament (ACL) injury. ACL injuries most frequently occur in sports involving sudden knee-bending movements, such as soccer, basketball, professional wrestling, martial arts, artistic gymnastics, and alpine skiing (Contreras, 2024). In Indonesia, sport-related injuries constitute the second most common type of accident, after domestic accidents (3.7%) and occupational accidents (3.1%) (Nurrokhmah & Anggita, 2024). This pattern is also evident in a survey of members of the Indonesian ACL Community (Central Java–Yogyakarta branch) reported that ACL injuries arose from both non-contact and contact factors, and that these injuries occurred far more frequently during sporting activity than during non-sporting activity. Changing direction and stopping suddenly was the most common non-contact cause, while being kicked, bumped, or tripped was a more common contact cause than a direct blow to the outer knee or lower leg (Gusma, 2022).

Badminton is a sport prone to injuries. However, it is not considered a contact sport because players are separated by a net (Huxel Bliven & Anderson, 2013). The percentage of sports injuries caused by non-body contact are ankle injuries at 53.33% and knee injuries at 46.66% (Hotwani, 2021). Although badminton is a non-contact sport, previous studies have reported that badminton injuries account for 1%–5% of all sports injuries (Zaidan et al., 2024), indicating that the repetitive rapid forward movements during badminton matches create high stress loads, particularly on the Achilles and patellar tendons in the dominant leg. More broadly, the speed- and reaction-dependent footwork of badminton makes targeted physical conditioning important from a young age; jump-rope (skipping) training, for example, has been shown to improve sprint speed and whole-body reaction time in U-15 female badminton players (Isauraya et al., 2025).

In badminton, a complex sport, it is not uncommon for players to sustain injuries, whether during matches or training. According to WHO data (2015), the risk of athletes sustaining injuries from playing badminton is estimated at 108 cases, or 10.84% of 1,000 matches (Zaidan et al., 2024). The landing phase of the explosive jumping smash has been identified as a key mechanism of knee-injury risk; a biomechanical analysis of youth badminton athletes reported that mismatched knee flexion angles and foot positioning during landing were significant risk factors for knee injury, particularly to the anterior cruciate ligament (ACL), with such injuries tending to occur in the non-dominant (landing) leg (Fatma & Irawan, 2025). Data from another study by the Sports Medicine Unit at the University of Malaya indicates that among 33 young badminton players who sustained sports injuries, there were 21 cases of injury in male adolescents and 12 cases in female adolescents (Ashfahani, 2020). Of these, 5 (10%) athletes reported upper-body injuries, 24 (48%) reported lower-body injuries, and 21 (42%) reported having experienced injuries in both areas. Additionally, 27 (54%) athletes reported muscle strains (e.g., cramps, muscle tears, hamstring injuries, etc.), and 23 (46%) athletes reported joint injuries (sprains), such as ankle, knee, and shoulder injuries, among others.

Running, although a non-contact endurance sport, carries a high injury burden. A one-year prospective cohort study of recreational runners found that 52% sustained a running-related injury, with calf strain (15%), Achilles tendon injury (11%), and plantar fasciopathy

(9%) being the most common diagnoses and injured runners missing an average of 56 days of training; a prior injury within the previous year, reduced navicular drop, and altered knee, hip, and pelvis running mechanics were among the factors associated with increased odds of injury (Dillon et al., 2023). The repetitive ground impact and continuous loading of the lower limbs make the knee a primary site of overuse injury in runners, who depend heavily on lower-limb strength, muscle flexibility, and muscular endurance to sustain performance. Accordingly, targeted resistance methods such as eccentric isotonic training have been shown to develop leg-muscle strength endurance and improve middle-distance (800 m) running performance in youth runners (Faraj & Jabbar, 2025). In badminton, by comparison, most injuries (about 63.1%) occur in the lower extremity, notably the knee (37.1%) and ankle (28.3%) reflecting the rapid lunging and directional changes that load the dominant leg (Phomsoupha & Laffaye, 2020).

Football (soccer), by contrast, is a contact sport with high physiological demands. Frequent body contact between players and the prolonged 2×45-minute match duration substantially increases the risk of injury (Buckthorpe et al., 2025), while high-intensity, repetitive actions such as jumping, sprinting, sudden changes of direction, and tackling, often performed under fatigue, expose the knee to injury (Makuch et al., 2024). Approximately 55% of sport-activity injuries involve the knee, with footballers, runners, basketball players, and athletics competitors at particularly high risk because the knee acts as the main weight-bearing joint; common knee injuries in footballers include medial collateral ligament, meniscus, and anterior cruciate ligament damage (Stirton et al., 2021).

Basketball shares many of these mechanisms. As a sport characterized by frequent jumping, landing, pivoting, and rapid acceleration-deceleration, it places heavy load on the knee, and injuries commonly arise through non-contact mechanisms involving knee valgus and twisting (Zhang, 2025). During landing in particular, the knee joint is subjected to excessive loading and therefore requires adequate lower-limb muscle endurance and strength to maintain balance and reduce injury risk (Taylor et al., 2020). Leg-muscle power is likewise central to basketball performance; a study of youth players reported that leg-muscle explosive power was very strongly correlated with jump-shoot ability and accounted for roughly 73% of its variance (Dewi Wahyuni & Cahya Setia, 2021). Taken together, these four disciplines (badminton, running, football, and basketball) differ in their movement demands and contact characteristics, yet all expose athletes to a high risk of knee injury; this shared vulnerability across contact and non-contact sports is the rationale for selecting athletes from across these four sports in the present study.

Core stability training (CST) can help improve dynamic balance and muscle coordination between the upper and lower extremities, as well as reduce the risk of injury and muscle imbalances (Gunistry & Singh, 2025). CST can help improve postural body control. This is supported by previous research indicating that repetitive core exercises combined with limb movements appear to enhance postural control (Alaa El-din A. Balba & Ahmed H. Waly, 2018). During the performance of sports skills, stable core muscles provide a foundation upon which the upper and lower extremity muscles can accelerate body segments and transfer force between distal and proximal body segments (Chevidikunnnan et al., 2016). Core muscle strengthening can help improve dynamic balance and muscle coordination between the lower and upper extremities, as well as reduce the risk of injury and muscle imbalance (Ma et al., 2024).

Core stability exercises aim to improve stability and balance, enhance sensorimotor function, and enable the body to move effectively and efficiently (Behm et al., 2023). Core stability exercises can build strength in the postural muscles, which improves trunk stability and posture, thereby enhancing balance. Additionally, improvements in core stability are accompanied by hip and knee extension movements, increased strength in the ankle muscles, and enhanced nerve conduction. Core stability training establishes a connection between core

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stability and the hip, knee, and ankle. This is because all parts of the body are interconnected, either directly or indirectly (Afridi et al., 2023).

Joint flexibility is essential for human movement and mobility. This aligns with research (Setyorini & Setyaningrum, 2019), which explains that daily activities require soft tissue flexibility. A decline in flexibility leads to a series of limitations, ranging from reduced ability to perform simple tasks such as sitting or dressing to impaired movement coordination. Therefore, flexibility is crucial for normal movement. Maintaining it is essential to prevent musculoskeletal disorders. Flexibility refers to the ability of joints and muscles to move to their full extent within a wide range of motion. To enhance flexibility and prevent injuries, stretching techniques have become an integral part of sports training programs. In addition to being beneficial for stretching joints, flexibility also plays a role in preventing injuries in athletes. (Behm et al., 2023) explain that in addition to improving flexibility, stretching can also play a role in preventing sports injuries. Furthermore, other researchers explain that poor flexibility can be an indirect cause of injury (Hotwani, 2021). Specific stretching techniques, in particular proprioceptive neuromuscular facilitation (PNF), have likewise been shown to enhance flexibility in athletes; a study of football players reported that a PNF program improved Sit-and-Reach flexibility by 23.8% and, at the same time, improved agility (Illinois agility test) by 12.26% (Bintang et al., 2025).

From the explanation above, it can be concluded that core muscle strength can create and improve body stability, coordination between the upper and lower extremities, reduce injuries, and enhance body balance. Thus, with a balanced body, a person will be able to move quickly in various directions without losing balance; this is also referred to as a person's agility. The CST training method plays a very important role in improving a person's coordination and body balance. Core muscles are located in the vertebral column and around the abdominal cavity. Depending on their role and characteristics, core muscles can be divided into deep and superficial core muscles; the former includes the transverse abdominis and multifidus muscles, while the latter comprises the rectus abdominis, the internal and external oblique muscles, and the lumbar spinal muscles. Strengthening the core muscles can result in smaller shifts in the mediolateral center of pressure and also in the center of mass. This means that movements at the trunk and hip levels are well-controlled, leading to a significant improvement in dynamic balance.

Although core stability training has been widely investigated, most prior research has focused on injury prevention, performance enhancement, or the rehabilitation of low-back pain rather than on knee-injury recovery specifically. Earlier studies have shown that CST programs reduce the incidence of knee injury and improve proprioception and dynamic balance following ACL reconstruction (Alaa El-din A. Balba & Ahmed H. Waly, 2018), and that coordinated core musculature lowers the risk of abnormal movement patterns associated with sports injury. Other knee-injury rehabilitation approaches have relied on isometric quadriceps and hamstring exercises, eccentric exercise, range-of-motion exercise, or modalities such as low-level laser therapy. However, these studies have generally examined a single sport or a single clinical population, used only one outcome measure, and rarely paired leg-muscle stabilization with joint flexibility as joint indicators of recovery across several sports at once. There is therefore a gap concerning the effect of CST on lower-limb muscle stabilization and flexibility during the recovery phase of athletes drawn from multiple, biomechanically distinct sports, the gap that the present study seeks to address.

The research questions in this study are: "Does core stability training affect improvements in lower limb muscle stabilization during knee injury recovery?" and "Does core stability training affect improvements in flexibility during knee injury recovery?" The objectives of this study are to determine whether core stability training affects the improvement of lower limb muscle stabilization during knee injury recovery, and whether core stability

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training affects the improvement of flexibility during knee injury recovery. This study is an experimental study, with a population of 18 athletes from four sports disciplines in Bandung, West Java.

The novelty of this study lies in applying core stability training as a recovery intervention for ACL/PCL knee injuries simultaneously across four biomechanically distinct sports which are badminton, running, football, and basketball and in evaluating two complementary recovery indicators together: lower-limb muscle stabilization (assessed with the single-leg squat test) and knee-joint flexibility (assessed with goniometric range of motion). To the authors' knowledge, few studies have combined these two outcomes within a single true-experimental design involving athletes from both contact and non-contact sports who are recovering from knee injury, which distinguishes the present work from earlier single-sport or single-outcome research.

Based on the points outlined above, this study found that core stability training has a significant effect on improving lower limb muscle stabilization during knee injury recovery, and that core stability training has a significant effect on improving flexibility during knee injury recovery.

Materials and methods**Study participants**

The study involved 18 male athletes from Bandung City, West Java, Indonesia, who were recovering from knee injuries, specifically injuries to the Anterior Cruciate Ligament (ACL) and Posterior Cruciate Ligament (PCL). The participants were drawn from four different sports representing both physical-contact and non-contact disciplines: football (soccer) and basketball as the contact sports, and badminton and running as the non-contact sports. All participants had sustained their knee injuries approximately six months prior to the study. The population was identified as athletes from four sports (badminton, running, football, and basketball) in Bandung, West Java, who were recovering from knee injuries. Second, formal permission letters were submitted to, and written approval was obtained from, the management of each participating club (Holspec, Saint Prima Football Academy, Garuda Bandung Basketball, and the UPI Badminton student activity unit). Third, athletes were screened against the inclusion criteria: male sex, a diagnosed ACL or PCL injury sustained approximately six months earlier, and current participation in one of the four sports. Because the eligible population numbered fewer than 100, a total sampling technique was applied, in which every member of the population was used as the sample, yielding 18 athletes. Fourth, a pre-test was administered to all participants, after which the 18 athletes were divided into two equal groups of nine through random assignment; subject-matching ordinal pairing (the AB-BA formula) was then used to balance the baseline ability of the experimental and control groups. Using a total sampling technique combined with random assignment, the 18 athletes were divided equally into two groups of 9 athletes each: an experimental group that received the Core Stability Training (CST) intervention, and a control group that received conventional (strength) training. Group allocation was performed by having participants draw numbered slips (1–18), with odd-numbered participants assigned to Group A (experimental) and even-numbered participants assigned to Group B (control). To ensure baseline equivalence, a subject-matching ordinal pairing procedure using the AB-BA formula was applied so that both groups had comparable initial ability levels.

Study organization

The research employed an experimental method with a pre-test/post-test control group design (true experimental design) to examine the causal influence of CST on leg muscle stabilization and knee joint flexibility during knee injury recovery. The study was conducted at

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the FPOK Cicaheum campus, Universitas Pendidikan Indonesia, Bandung. Two measurement instruments were used for data collection. The Single Leg Squat (SLS) test was administered to assess leg muscle strength and stabilization, where lower post-test scores indicate better stabilization performance. A goniometer was used to measure the Range of Motion (ROM) of the knee joint in degrees, serving as the indicator of joint flexibility. The experimental procedure followed a three-stage algorithm. First, a pre-test (O_1) was administered to both groups to establish baseline measurements of leg muscle strength (via SLS) and knee joint flexibility (via goniometer). Second, the treatment phase was conducted over 12 sessions scheduled across several weeks: the experimental group performed the CST program (X_1), consisting of posterior pelvic tilt exercise, bridging exercise, bird-dog exercise, and wall squat exercise, designed to strengthen the core muscles and lower extremity stabilizers, while the control group followed a conventional strength training program (X_2) for the same duration. Third, upon completion of the 12-session intervention, a post-test (O_2) was administered using the same SLS and goniometer instruments to measure final leg muscle stabilization and knee joint ROM, enabling comparison of the treatment effects between the two groups.

The treatment programs administered to the two groups are described as follows. Both groups trained three times per week (Monday, Thursday, and Saturday) for a total of 12 sessions, a dosage chosen because previous work indicates that 12-16 sessions are sufficient to produce a stable training adaptation (Fitriadi, 2021). The experimental group (Group A) performed a structured Core Stability Training program comprising seven exercises (elbow plank, Russian twist, supine bridge, supine unilateral bridge, side bridge, bird-dog, and dead bug). Each exercise was held for 15 seconds and progressed from 2 up to 5 sets over the course of the program, with approximately 60 seconds of rest between sets, in order to strengthen the core muscles and the lower-extremity stabilizers (Huxel Bliven & Anderson, 2013). The control group (Group B) followed a conventional strength-training program of equal frequency and duration but without the core-stabilization component. To minimize threats to internal validity, both groups were assessed with identical instruments at the same venue during the pre-test and post-test, light refreshments were provided during sessions to reduce participant drop-out, and group allocation was randomized so that the experimental and control conditions were treated equitably.

Statistical analysis

Data analysis was performed using SPSS software and followed a sequential procedure. First, descriptive statistics (mean $\pm$ standard deviation) were calculated for both pre-test and post-test scores of ROM and SLS across groups, and a percentage change was applied to quantify the magnitude of improvement. Second, a normality test was conducted using the Shapiro-Wilk test, appropriate for sample sizes below 50, with a significance threshold of $p > 0.05$ indicating normal distribution. The ROM data were found to be normally distributed (all p -values > 0.05), while the SLS data did not meet the normality assumption ($p < 0.05$). Third, based on the normality results, the choice of hypothesis test was determined accordingly: a parametric paired/independent t-test was used for the ROM data, whereas a non-parametric Wilcoxon test was applied to the SLS data to analyze differences within and between the experimental and control groups. The significance criterion for accepting the research hypotheses was set at $p < 0.05$, meaning that a p -value below this threshold confirmed a statistically significant effect of CST on the measured variables. Additionally, a sport-specific comparison analysis was conducted to examine changes across the four sports, although the limited sample size per sport reduced the representativeness of those sub-group findings.

Results

The following shows the results of leg muscle strength and knee joint angle tests for athletes with knee injuries using the CST method. Table 1 shows the pretest and posttest scores. Figure 1 presents a graphical comparison of the changes derived from Table 1.

Table 1. Descriptive analysis of Range of Motion (ROM)

Group		Pretest (°)	Posttest (°)
A	$\bar{X} \pm SD$	81.11 $\pm$ 4.86	127.11 $\pm$ 2.57
B	$\bar{X} \pm SD$	82.22 $\pm$ 5.65	113.11 $\pm$ 3.18

Notes:

A: CST Treatment

B: Control Treatment

$\bar{X} \pm SD$: Mean and Standard Deviation

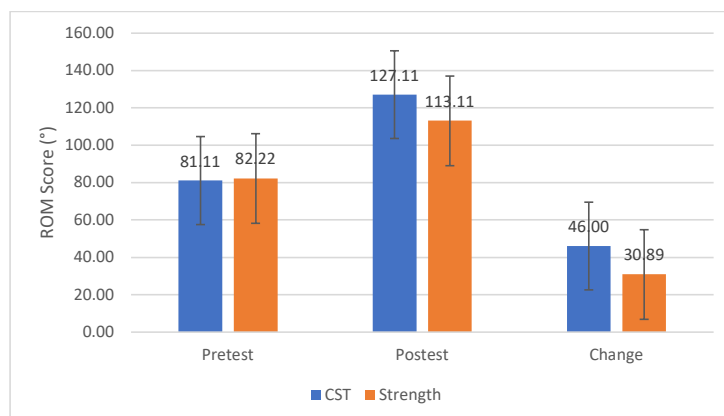


Figure 1. Changes in knee joint ROM scores before and after CST

The results presented in Table 1 indicate that the mean ROM value of the knee joint among athletes from the four sports prior to the intervention using the CST method was 81.11°. A comparable value was observed in the control training method, which yielded a mean of 82.22°. Following the implementation of the two different training methods, the ROM values of the knee joint demonstrated notable changes in both groups. In the CST method, the mean ROM value of the knee joint increased to 127.11°, whereas the mean ROM value under the control training method reached 113.11°. Upon closer examination, it is evident that the mean ROM of the knee joint obtained through the CST method was superior to that achieved through the control training method.

Table 2. Descriptive analysis of Single Leg Squat (SLS)

Group		Pretest (score)	Posttest (score)
A	$\bar{X} \pm SD$	4.67 $\pm$ 0.50	0.11 $\pm$ 0.33
B	$\bar{X} \pm SD$	4.56 $\pm$ 0.53	2.44 $\pm$ 0.53

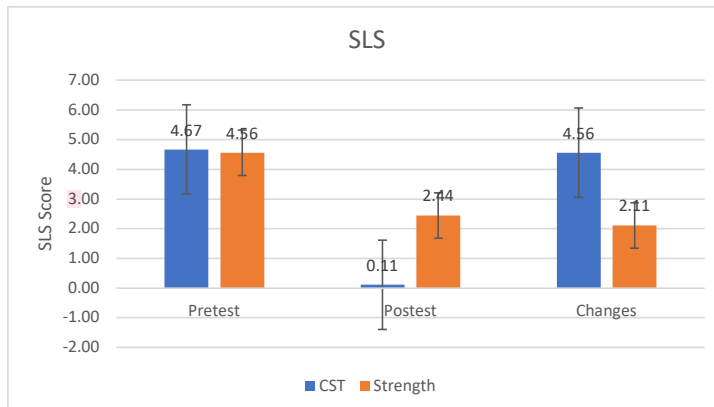


Figure 2. Changes in SLS performance between pretest and posttests using CST

As shown in Table 2 and Figure 2, the average SLS score of athletes from the four sporting disciplines before receiving the CST intervention was 4.67, with the control group demonstrating a closely aligned initial score of 4.56. After both groups completed their respective training programs, a considerable decline in SLS scores was observed as a reduction that reflects improved leg muscle stabilization. Athletes in the CST group achieved a notably lower post-intervention mean of 0.11, whereas those in the control group recorded a mean of 2.44. These figures clearly demonstrate that the CST method was markedly more effective in enhancing leg muscle stabilization than the control training approach.

To determine the percentage of change between the pretest and posttest results under each training method, a growth analysis of the mean score variation was conducted using the formula presented below.

$$\%change = \left(\frac{Posttest\ score - Pretest\ score}{Pretest\ score} \right) \times 100\%$$

Using this formula, the average change in scores between the pretest and posttest is shown in Table 3.

Table 3. Change percentage of ROM

Group		Pretest Posttest change (%)
A	$\bar{X} \pm SD$	36.22 ± 2.89
B	$\bar{X} \pm SD$	27.37 ± 3.30

Based on the results in Table 3, it can be seen that the average change in knee joint ROM using the core stability training (CST) method was 36.22%. Meanwhile, the average knee joint ROM in the sample group using the control exercise method showed a change of 27.37% from the baseline value. In the next section, a test will be conducted to prove the significance of the CST exercise method's effect on the recovery of athletes with knee injuries.

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Table 4. Change percentage of SLS

Group	Pretest Posttest change (%)	
A	$\bar{X} \pm SD$	97.22 ± 8.33
B	$\bar{X} \pm SD$	46.67 ± 7.07

Based on the results in Table 4, it can be seen that the average change in SLS using the CST method was 97.22%. Meanwhile, the average SLS value in the sample using the control training method showed a change of 46.67% from the baseline value. In the next section, a test will be conducted to prove the significance of the CST method's effect on the recovery of athletes with knee injuries.

Table 5. ROM Comparison Test Results Per Sport

Sport	Group		p value
	CST (°)	Strength (°)	
Pretest			
Badminton	82.5	87.5	0.221
Runner	87.5	80.0	0.102
Basketball	76.7	78.3	0.796
Football	80.0	85.0	0.317
Posttest			
Badminton	129.0	116.0	0.121
Runner	130.0	113.0	0.121
Basketball	125.3	110.7	
Football	125.0	114.0	
Change			
Badminton	36.0	24.6	0.121
Runner	32.7	29.2	0.121
Basketball	38.8	29.3	0.050
Football	36.0	25.5	0.121

Based on the summary of scores by sport in Table 5, in the CST group, the largest average change was found in basketball. Meanwhile, the lowest average change was found in track and field. In the strength group, the largest average change was found in track and field and basketball, while the lowest average change was found in soccer. Furthermore, the results of the statistical test indicate that when calculated by sport, the probability values are greater than 0.05, even though significant differences are apparent between them. This is because the sample data for each sport is insufficient (non-representative), resulting in an inaccurate assessment.

Table 6. SLS Comparison Test Results Per Sport

Table 6. SLS Comparison Test Results Per Sport			
Sport	Group		p value
	CST (score)	Strength (score)	
Pretest			
Badminton	5.0	4.5	0.317
Runner	4.5	5.0	0.317
Basketball	4.7	4.7	1.000
Football	4.5	4.0	0.317
Posttest			

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Badminton	0.0	2.5	0.102
Runner	0.0	2.5	0.102
Basketball	0.3	2.7	0.043
Football	0.0	2.0	0.083
Change			
Badminton	100.0	45.0	0.102
Runner	100.0	50.0	0.102
Basketball	91.7	43.3	0.043
Football	100.0	50.0	0.083

Based on the results of the SLS score summary by sport, in the CST group, the largest average change was found in badminton and track and field. Meanwhile, the lowest average change was found in basketball. Meanwhile, in the strength group, the largest average change was found in badminton. Meanwhile, the lowest average change was found in basketball. Furthermore, the results of the statistical test indicate that when calculated by sport, the probability value is greater than 0.05, even though there appears to be a significant difference between the two. This is because the sample data for each sport is insufficient (not representative), resulting in an inaccurate assessment.

Discussion

Based on the findings and analysis of data obtained from pre- and post-tests, one exercise method for improving lower limb muscle stability and flexibility during knee injury recovery is core stability training (CST). This study tested the use of core stability training for recovery in athletes from badminton, running, soccer, and basketball who had sustained knee injuries. CST can improve muscle coordination in the upper and lower extremities and enhance agility. Additionally, CST is effective in protecting athletes from the risk of injury. Other studies also confirm that CST is a crucial foundation for improving physical fitness (Oktaviyani & Arifin, 2021).

Another study explains that core muscle training is useful for reducing back pain and can help maintain proper body posture (Karokaro & Hutabarat, 2018). Core muscles play a crucial role in maintaining stability and coordination between the upper and lower extremities, which is vital in reducing the risk of injury among athletes. Therefore, physiologically, the level of knee injury in this study was assessed based on joint range of motion and lower limb muscle stabilization.

1. The Effect of CST on Improving Lower Limb Muscle Stabilization

The results of this study indicate that CST can improve lower limb muscle stabilization. Core stability training is an exercise concept designed to train the stabilizing muscles of the trunk, pelvis, and lower extremities. This training aims to train postural muscles to contract and coordinate optimally in order to maintain proper body posture and balance. Core stability training, which enhances stability, serves as part of clinical prevention and rehabilitation for patients. It encompasses a series of exercise programs with diverse approaches that share the common goal of improving lower extremity control. These exercises are designed to enhance the capabilities of the neuromuscular and motor control systems to prevent injuries (Anjasmara et al., 2021).

CST is a crucial component of efficient athletic movement. This is often achieved through the kinetic chain, coordination, and a sequence of activities involving the distal body parts in an optimal posture, which enables athletic movement. In this context, core muscles play a vital role in generating strength, balance, and reducing the risk of injury; they are considered the central hub for controlling strength, balance, and optimal movement, whether in the upper or lower extremities. This exercise is one of the most effective and efficient ways to improve

balance, as it can be performed not only in a clinic with the assistance of a physical therapist but also at home (Zemková & Zapletalová, 2022).

The core is a group of trunk muscles that surround the abdominal cavity and the spine. Core muscle strengthening is used to train the control of the muscles needed to maintain functional stability around the lumbar spine (Gulrandhe & Kovala, 2023). The core muscles can stabilize the body, allowing it to move in all directions, even on the most uneven terrain, or to stand in one place without losing balance. In this way, core exercises can reduce the risk of falling.

Core muscle strength is essential for improving body balance and postural control during activities such as landing and contact. The pelvis, spine, and kinetic chain all require core stability for optimal load distribution. CST emphasizes the strength and conditioning of local and general trunk muscles that work together to stabilize the spine. CST performed with a stable spine has a positive effect on postural control, and postural stability can be fully improved through this training (Yakut & Talu, 2021). Core stability exercises are believed to maintain spinal stability by activating the core muscles, diaphragm, abdominal muscles, and pelvic floor muscles (Lee, 2023). Additionally, CST is known as a highly effective exercise method for strengthening muscles and improving lumbar stability and flexibility (Segita, 2021).

Physiologically, the muscles in the core region provide a stable foundation for mobility while protecting the body from disturbances by creating a rigid cylinder and a state of muscle immobility. Additionally, the proprioceptive system gathers information from the joints and muscles to coordinate subconscious reflexes that maintain balance. Stability can change instantly in response to postural adjustments or external loads on the body. The nervous subsystem must work in concert to ensure sufficient stability while also enabling desired joint movement. Tension in the core muscles is controlled by the nervous subsystem. When tension increases within these muscles, the overall strength between the lumbar vertebrae also increases, which can reinforce the lumbar spine to enhance stability. The transverse abdominis is the primary muscle that works with the nervous system to ensure adequate stability (Marani et al., 2020). Thus, it can be concluded that the core muscle system and stability are closely related.

If an athlete lacks proper core stability, their movements will not be optimal, which can hinder the injury healing process. Abnormal movement patterns lead to poor technique and increase the risk of recurrent injuries, as well as slow down the recovery process. Therefore, injuries must be addressed as soon as possible and followed by strength training therapy. Based on the views of the researchers above, it can be concluded that core stability training can reduce the risk of injury and assist in the rehabilitation of athletes post-injury to help them regain their performance (Majewska et al., 2022).

2. The Effect of CST on Improving Flexibility

Core stability training refers to the ability to control the position and movement of the body's core. Core stability training helps maintain good posture during movement and serves as the foundation for all arm and leg movements. This indicates that optimal postural stability facilitates the activation of core stability muscles (Huxel Bliven & Anderson, 2013) (Huxel, Bliven, & Anderson, 2013).

Core stability training is defined as exercises designed to enhance neuromuscular function. These exercises aim to improve control and flexibility. This increased flexibility can be achieved in two ways: first, by enhancing muscle coordination and control, and second, by increasing muscle strength through various core stability training methods. The effects of core stability training develop the dynamic function of the core muscle group. Through coordinated and simultaneous (co-contraction) muscle contractions, these muscles provide rigidity to the spinal column to support the trunk. Consequently, intradiscal pressure decreases, reducing the workload on the lumbar muscles and lower extremities (such as the hip and knee joints) thereby

preventing tissue injury and reducing abnormal lumbar muscle tension (Wisnubrata & Zharfan, 2020).

As the muscles relax, it is expected that muscle pump function will improve, leading to increased blood circulation to the back muscles. Consequently, the supply of nutrients and oxygen to the muscle tissue improves, and pain caused by spasms is reduced. Additionally, by activating the core muscles (which function as spinal stabilizers) the surrounding muscles that were previously in spasm will relax (Fatahi et al., 2019). Core stability exercises can enhance flexibility, strength, and power in both the upper and lower extremities. Furthermore, core stability can help optimize the strength of the leg muscles during movement (Mohammed et al., 2022).

Joint flexibility refers to the maximum range of motion that a joint can achieve, encompassing the relationship between the joint structure, muscles, tendons, and ligaments surrounding the joint (Prabowo & Syahlaa, 2023). According to Segita (2021), flexibility is the ability of muscles to stretch or lengthen as much as possible so that the body can move through the full range of joint motion without pain. Range of motion (ROM) exercises are exercises that move joints as optimally and extensively as possible within an individual's capacity, without causing pain in the moved joint. Additionally, ROM exercises can improve joint flexibility and muscle strength and are isometric exercises that can maintain or increase muscle strength and endurance, as well as prevent the progression of joint capsule degeneration, ankylosis, and contractures. Based on existing research, it has been proven that these active-assisted ROM exercises can increase joint range of motion (Setyorini & Setyaningrum, 2019).

During ROM exercises when a joint is moved, the cartilage between the two bones rubs against each other. Cartilage contains many proteoglycans attached to hyaluronic acid, which is hydrophilic, so cartilage contains a lot of water; cartilage contains 70–75% water. Pressure on the cartilage pushes water out of the cartilage matrix into the synovial fluid. Pressure on the cartilage pushes water out of the cartilage matrix into the synovial fluid. When the pressure ceases, the water that has moved into the synovial fluid is drawn back in along with nutrients from the synovial fluid (Indrayana & Wahyudi, 2020). In addition to Range of Motion (ROM) exercises, improved flexibility can also be achieved through CST, particularly in the lumbar muscles. CST also plays a role in restoring coordination and control of the body's muscles to improve control of the lumbar spine and pelvis, regulate tension in the lumbo-pelvic-hip joint to maintain lumbar stability, strengthen muscles, enhance physical endurance, and improve posture (Luberto et al., 2024).

This study examines muscle function during the injury recovery phase, in which muscles are trained through core stability exercises to restore normal function, as measured by range of motion (ROM). For an athlete to achieve optimal results in the injury recovery process, the physiological aspects must be taken into account. From a physiological perspective, several muscles that support the knee joint can be divided into two groups: the large quadriceps muscles (rectus femoris, vastus lateralis, vastus intermedius, and vastus medialis), the hamstring muscles, and some leg muscles (Angullo-Gómez et al., 2023).

After performing core stability exercises consisting of the posterior pelvic tilt exercise, bridging exercise, bird-dog exercise, and wall squat exercise. This intervention was administered to strengthen and improve core muscle and lower extremity muscle stabilization, thereby helping to reduce pain and improve patients' functional activity based on ROM measurements (Salsabila & Karnadipa, 2021). In summary, this study demonstrates that FR can be applied as an effective technique to improve ROM in standing and reaching tests over an 8-week training period without a decrease in core "endurance strength," balance, and jumping ability.

Examined by individual sport, the results in Tables 5 and 6 show that the benefit of CST was consistent across all four disciplines, although its magnitude varied with the movement

demands of each sport. For knee-joint flexibility (ROM), the largest improvement in the CST group occurred in basketball (38.8%), followed by football and badminton (36.0% each), with running showing the smallest (though still substantial) change (32.7%). This pattern is consistent with the biomechanics of basketball and football, in which repeated jumping, landing, and pivoting place the greatest demand on knee range of motion, so that restoring full ROM produces the most visible gains in these athletes. The frequent body contact and high-intensity actions characteristic of football, together with the repeated landing loads of basketball, also help to explain why these contact sports benefited most clearly in terms of joint flexibility.

For lower-limb muscle stabilization (SLS), the CST group reached near-complete recovery in badminton, running, and football (100% change) and a slightly lower value in basketball (91.7%), in every case markedly exceeding the corresponding control-group values. The strong response in badminton and running is plausible because these non-contact sports rely heavily on single-leg loading and rapid directional lunging, for which a stable core and well-controlled lower-limb stabilizers are essential; CST directly trains the trunk-to-limb kinetic chain that underpins this control. Although the per-sport probability values exceeded 0.05—reflecting the small number of athletes within each sport rather than an absence of effect—the uniformly large percentage changes indicate that CST is beneficial for knee-injury recovery across both contact (football, basketball) and non-contact (badminton, running) sports. These sub-group findings should nonetheless be interpreted with caution given the limited and non-representative sample size per sport, and they warrant confirmation in larger, sport-specific studies.

Conclusions

Based on the research results, calculations, and data analysis, the researchers can draw the following conclusions regarding the Effect of CST on Improving Leg Muscle Stabilization and Flexibility in Knee Injury Recovery:

1. There is a significant effect of CST on improving leg muscle stabilization in knee injury recovery.
2. There is a significant effect of CST on improving flexibility in knee injury recovery.

The results of this study indicate that the effect of core stability training on improving leg muscle stabilization and flexibility in knee injury recovery can improve leg muscle stability and flexibility after training with adjusted intensity in a core stability training (CST) program, as measured by single-leg squats and range of motion (ROM) tests in athletes recovering from knee injuries. This occurs because when athletes perform CST training as part of injury rehabilitation to improve core muscle stabilization, it can reduce the load pressure on the lower extremities. Therefore, core strength training (CST) can be used in periodized training programs for strengthening injuries as part of the knee injury rehabilitation process.

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