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Unilateral Hamstring Muscle Strengthening Exercises Can Improve Hamstring Asymmetry and Increase Jumping Performance in Sub-Elite Badminton Athletes

Los ejercicios unilaterales de fortalecimiento de los músculos isquiotibiales pueden mejorar la asimetría de los isquiotibiales y aumentar el rendimiento de salto en atletas de bádminton de sub-élite

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Abstract. This study aimed to determine the effect of 10 weeks of unilateral training on asymmetry and jumping performance in sub-elite badminton athletes. 23 out of 41 badminton athletes who met the inclusion criteria were taken as samples in this study. Selected samples will be given unilateral exercise interventions in the form of Swiss ball hamstring curl exercises and single leg bridge for ten weeks with a frequency of exercise 3 times a week. Data were collected two times before the intervention (pretest) was given and after the intervention (posttest). The measurement uses the Norbord test to determine the condition of hamstring asymmetry and the Counter Movement Jump (CMJ) jump test to determine jump height. The results showed that there was a significant decrease in the percentage of hamstring asymmetry $p \leq 0.001$ (Pretest: 20.26±10.25 % to Posttest: 9.20±3.51 %) and has a large effect size with a Cohen's d value of 1.443, and an increase in jump height $p \leq 0.001$ (Pretest: 33.06±4.93 cm to Posttest: 35.17±4.54 cm) and has a medium effect size with a Cohen's d value of 0.447. The conclusion is that 30 unilateral exercises for ten weeks can improve hamstring asymmetry above 10% and increase jumping performance in badminton athletes.
Keywords: Hamstring Asymmetry, Jump performance, Unilateral exercise

Resumen. Este estudio tuvo como objetivo determinar el efecto de 10 semanas de entrenamiento unilateral sobre la asimetría y el rendimiento de salto en atletas de bádminton de subélite. En este estudio se tomaron como muestras 23 de 41 atletas de bádminton que cumplieron con los criterios de inclusión. Las muestras seleccionadas recibirán intervenciones de ejercicio unilaterales en forma de ejercicios de curl de isquiotibiales con pelota suiza y puente de una sola pierna durante diez semanas con una frecuencia de ejercicio 3 veces por semana. Los datos se recopilaron dos veces antes de realizar la intervención (preprueba) y después de la intervención (postprueba). La medición utiliza la prueba de Norbord para determinar la condición de asimetría de los isquiotibiales y la prueba de salto de salto con contramovimiento (CMJ) para determinar la altura del salto. Los resultados mostraron que hubo una disminución significativa en el porcentaje de asimetría de los isquiotibiales $p \leq 0,001$ (Pretest: 20,26±10,25 % a Postest: 9,20±3,51 %) y tiene un tamaño de efecto grande con un valor d de Cohen de 1,443, y un aumento en altura de salto $p \leq 0.001$ (Pretest: 33.06±4.93 cm a Postest: 35.17±4.54 cm) y tiene un tamaño del efecto medio con un valor d de Cohen de 0.447. La conclusión es que 30 ejercicios unilaterales durante diez semanas pueden mejorar la asimetría de los isquiotibiales por encima del 10% y aumentar el rendimiento de salto en deportistas de bádminton.
Palabras clave: Asimetría de los isquiotibiales, rendimiento del salto, ejercicio unilateral

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Introduction

Imbalance or Asymetry is a natural condition in humans, but in the world of sports, excessive asymmetry is considered detrimental because it can interfere with sports performance and increase the risk of injury (Afonso *et al.*, 2022). A significant imbalance between the strength of the right and left hamstring muscles causes the condition of hamstring asymmetry (Mrzygłód *et al.*, 2021). The hamstrings are an important muscle group that flexes the knee, concentrically extends the hips, and participates in tibial rotation (Schache *et al.*, 2013). This muscle group comprises M. Semimembranosus, M. Semitendinosus, and M. Biceps Femoris. The hamstring muscle is a mixed type of muscle consisting of type I, M. Semitendinosus. If there is a pathology, the muscle will experience tension and shortening or contractures, and type II, namely M. Semimembranosus and M. Bicep Femoris, if there is pathology, atrophy will occurs, or muscle weakness (Opar, Williams and Shield, 2012). The hamstrings also play a role in the control of knee extension and play an important role in sprint acceleration performance (Ishøi *et al.*, 2019). Meanwhile, less flexible hamstring muscles have been shown to affect posture and cause a posterior tilt of the pelvis (López-Miñarro *et al.*, 2012).

The length of the hamstring muscles is closely related to muscle strength; if a muscle shortens, the muscle strength will also decrease. When the hamstring muscles experience weakness, it will cause injury, especially in activities that involve running, stopping suddenly, or jumping, as in football, basketball, rugby, tennis, running, futsal, and badminton movements (Arnason *et al.*, 2008). *Badminton* is a sport that uses rackets with short and intermittent multi-direction movements (Phomsoupha and Laffaye, 2015; Sturgess and Newton, 2008). This sport requires players to perform five movements, such as changing direction (Sturgess and Newton, 2008), twisting and stretching (Ooi *et al.*, 2009), and lunging (Kuntze, Mansfield and Sellers, 2010) in response to their opponent's shot. With the shuttle traveling at speeds in the region of 50-70 $m.s^{-1}$ (110-155 mph) (Tsai *et al.*, 2008; Li *et al.*, 2017; Maloney, 2018), the player's need to travel as far as possible in shortest possible time is therefore apparent. The act of lunging would allow the player to cover an estimated distance of 1.5-foot lengths in less than one second (Kuntze, Mansfield and Sellers, 2010). For this reason, the lunge is an integral aspect of badminton.

The risk of injury can be reduced by increasing muscle strength (Chaabene *et al.*, 2019). Hamstring muscle strength is very important to ensure the balance of the hamstring quadriceps muscles to prevent strain on the hamstring muscles. In addition to preventing hamstring strains, strengthening the hamstring muscles is also part of preventing anterior cruciate ligament (ACL) injuries. Hamstring muscle strength also aims to stabilize the knee and assist the ACL in maintaining joint stability (Khoiriyah, 2014). Athletes who have suffered hamstring injuries can return to sports as soon as two months after strengthening therapy (Mendiguchia *et al.*, 2014). This is very detrimental because elite athletes are always required to compete, so if an athlete has a hamstring injury, they are likely to lose many competitions.

Sports training is often given as a therapy to improve the asymmetry of athletes (Bishop, Turner and Read, 2018; Bettariga, Turner, *et al.*, 2022). The exercises given for hamstring strengthening differ in strength and general conditioning (Bourne et al., 2017; Shield and Bourne, 2020). One of the exercises to strengthen the hamstring muscles is the single leg hamstring bridge and swiss hamstring leg curl exercises performed unilaterally. The single-leg bridge is performed by lying on the ground, one heel lifted straight up, and the hips bent about 45° (Freckleton, Cook and Pizzari, 2014). In contrast, the swiss hamstring leg curl is done by placing one foot on the ball and rolling it towards themselves. Unilateral training provides unique neuromuscular activation, may also correct asymmetry between the legs and improve subsequent performance (Bishop, Turner and Read, 2018). Other studies have also shown the benefits of unilateral training interventions in trained athletes (Appleby, Cormack and Newton, 2020).

The reason for this study is based on previous reports showing that hamstring asymmetry is important because it is associated with risk factors associated with the development of hamstring muscle strain injuries (Timmins *et al.*, 2016), which is followed by a decrease in ROM in the hip joint ((Bradley and Portas, 2007) and ankles (Gabbe *et al.*, 2006). Several studies also state that asymmetry that varies by 10% to 15% is considered an early indicator of a significant imbalance and is associated with a high risk of injury and low sports performance (Risberg *et al.*, 2018; Vargas *et al.*, 2019).

Material and Methods

Subjects

The research design used was a quasi-experimental group pre-post design, namely the type of experimental research, where observations were made twice, namely before (pre-test) and after the experiment (post-test) in one group. Samples were selected using a purposive sampling technique with inclusion criteria being male with an age range of 16-20 years, having normal BMI, not expseriencing hamstring or anterior ligament injuries or leg injuries for less than six months, not currently experiencing musculoskeletal and cardiovascular disorders and willing to participate in hamstring strengthening exercise intervention for ten weeks. The sample is also a sub-elite athlete in East Java, Indonesia, who has experience practising badminton for over five years and actively practices at least three times a week. Forty-one badminton athletes as a sample were obtained from 5 badminton clubs in East Java. The 41 athletes then underwent a hamstring asymmetry test using the Norbord test. The results showed that 23 athletes fulfilled the condition of hamstring asymmetry (Asymmetry > 10%), so they were selected as the research sample.

Procedure

The selected sample was given informed consent to express willingness to be the research sample. After agreeing to the informed consent process, ethical clearance is submitted to obtain permission to treat humans. The application for ethical clearance received approval from the Semarang State University Health Research Ethics Committee with number 334/KEPK/EC/2022.

Before being given the unilateral hamstring training treatment, the study sample was accustomed to doing unilateral hamstring exercises for two weeks with a total of 6 exercises to adapt the nerves and muscles and take advantage of the "repeated bout effect". After adaptation was given, the samples were rested for one week to eliminate the effect of training during the adaptation period. After rest, the sample was given unilateral hamstring exercises for ten weeks with a frequency of exercise 3 times a week. The forms of unilateral hamstring exercises carried out are Swiss ball hamstring curl and Single leg bridge exercises.

The Swiss ball hamstring curl exercise was performed by the subject lying on his back on the floor with the heel of one right/left foot on the ball, knees extended, and hands on the floor at the sides and palms facing down. Subjects were asked to bend their knee on the part of the leg above the ball while rolling the ball towards themselves, lifting their pelvis off the ground, and holding this position for about 1 second before slowly returning to the starting position by straightening the knee on either leg. He was on the ball, and the pelvis is lowered. Meanwhile, the single-leg bridge is done by lying on the ground with one heel lifted straight up and the hips bent at approximately 45°. Then the research subjects were instructed to push their heels down to lift their buttocks off the ground while crossing their arms over their chests. Hold this position for about 1 second, then slowly return to the starting position with your buttocks down toward the ground. This exercise is performed alternately between the right leg and left leg. The sets, repetitions and training intervals are arranged in the exercise program presented in Table 1.

Table 1.
Unilateral hamstring strengthening exercise program

Week	Exercise	Set	Repetition	Rest/Sets	Rest/Exercise
1	Single leg bridge (right)	3	16 rep	1 minutes	5 minutes
	Single leg bridge (left)	3	16 rep	1 minutes	5 minutes
	Swiss ball Hamstring curl (right)	3	16 rep	1 minutes	5 minutes
	Swiss ball Hamstring curl (left)	3	16 rep	1 minutes	5 minutes
2	Single leg bridge (right)	3	16 rep	1 minutes	5 minutes
	Single leg bridge (left)	3	16 rep	1 minutes	5 minutes
	Swiss ball Hamstring curl (right)	3	16 rep	1 minutes	5 minutes
	Swiss ball Hamstring curl (left)	3	16 rep	1 minutes	5 minutes
3	Single leg bridge (right)	3	18 rep	1 minutes	5 minutes
	Single leg bridge (left)	3	18 rep	1 minutes	5 minutes
	Swiss ball Hamstring curl (right)	3	18 rep	1 minutes	5 minutes
	Swiss ball Hamstring curl (left)	3	18 rep	1 minutes	5 minutes
4	Single leg bridge (right)	3	18 rep	1 minutes	5 minutes
	Single leg bridge (left)	3	18 rep	1 minutes	5 minutes
	Swiss ball Hamstring curl (right)	3	18 rep	1 minutes	5 minutes
	Swiss ball Hamstring curl (left)	3	18 rep	1 minutes	5 minutes
5	Single leg bridge (right)	4	18 rep	1 minutes	5 minutes
	Single leg bridge (left)	4	18 rep	1 minutes	5 minutes
	Swiss ball Hamstring curl (right)	4	18 rep	1 minutes	5 minutes
	Swiss ball Hamstring curl (left)	4	18 rep	1 minutes	5 minutes
6	Single leg bridge (right)	4	18 rep	1 minutes	5 minutes
	Single leg bridge (left)	4	18 rep	1 minutes	5 minutes
	Swiss ball Hamstring curl (right)	4	18 rep	1 minutes	5 minutes
	Swiss ball Hamstring curl (left)	4	18 rep	1 minutes	5 minutes
7	Single leg bridge (right)	4	20 rep	1 minutes	5 minutes
	Single leg bridge (left)	4	20 rep	1 minutes	5 minutes
	Swiss ball Hamstring curl (right)	4	20 rep	1 minutes	5 minutes
	Swiss ball Hamstring curl (left)	4	20 rep	1 minutes	5 minutes
8	Single leg bridge (right)	4	20 rep	1 minutes	5 minutes
	Single leg bridge (left)	4	20 rep	1 minutes	5 minutes
	Swiss ball Hamstring curl (right)	4	20 rep	1 minutes	5 minutes
	Swiss ball Hamstring curl (left)	4	20 rep	1 minutes	5 minutes
9	Single leg bridge (right)	5	20 rep	1 minutes	5 minutes
	Single leg bridge (left)	5	20 rep	1 minutes	5 minutes
	Swiss ball Hamstring curl (right)	5	20 rep	1 minutes	5 minutes
	Swiss ball Hamstring curl (left)	5	20 rep	1 minutes	5 minutes
10	Single leg bridge (right)	5	20 rep	1 minutes	5 minutes
	Single leg bridge (left)	5	20 rep	1 minutes	5 minutes
	Swiss ball Hamstring curl (right)	5	20 rep	1 minutes	5 minutes
	Swiss ball Hamstring curl (left)	5	20 rep	1 minutes	5 minutes

Table 1 shows a unilateral exercise in the form of a Swiss ball hamstring curl and single leg bridge exercise performed alternately on the right and left legs. The training load also increases in both sets and repetitions. This follows the principle of progressive overload training, where the training load given to athletes must be periodically progressively increased (Adrian and Petru, 2021).

Instrumented Nordic Test and CMJ Test

After practising 30 times for ten weeks, the research samples underwent a posttest with the same test, namely the Norbord test, to determine the condition of hamstring asymmetry (Cuthbert *et al.*, 2021; Bishop *et al.*, 2022). The Norbord test can measure an athlete's hamstring strength through a compact sensor, wirelessly and in real-time, developed with high technology. An athlete can be tested with Norbord in about 30 seconds with accurate and reliable results (Opar *et al.*, 2013; Ercan, Kerem and Kunduracioglu, 2019). Before carrying out the Norbord test, participants were allowed to warm up by doing Nordic movements for three trials. Participants then performed the test with a sifter on a platform with their ankles attached to a weight cell. They were instructed to lean forward as slowly as possible while resisting the movement with their hamstring muscles. The device measures the eccentric force exerted by the hamstring muscle complex when the muscle is elongated under a load, as shown in figure 1. During maximal eccentric resistance of the hamstrings, the peak force is measured in Newtons (N) (Chavarro-Nieto *et al.*, 2022). The difference in the right and left leg hamstring strength value is expressed in proportion. This test was carried out two times, namely before the unilateral exercise intervention (pretest) and after the unilateral exercise intervention (posttest). The condition of hamstring asymmetry that was sampled in this study was an asymmetry that was > 10% on the initial test.

Then do the test using a force plate with Counter Movement Jump (CMJ) to determine jump height (Cheah et al., 2017; Heredia-Jimenez and Orantes-Gonzalez, 2020; Gonzalez Vargas & Gallardo Pérez, 2023). The study by Bishop et al., (2017) stated that the jump height test could validly and reliably identify limb asymmetry profiles (Bishop

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et al., 2017). Participants step on the pre-calibrated force plate while wearing shoes. They were instructed to stand straight for 5 seco, then after the signal "go", the participants immediately jumped as high as possible and landed in the force plate area. Each participant is given the opportunity three times to do the maximum CMJ test, with a 1-minute rest interval for each test. The highest jump height value used in the research data (Gathercole, Stellingwerff and Sporer, 2015; Mizuguchi *et al.*, 2015; Anicic *et al.*, 2023).

Figure 1. Norbord test to determine hamstring muscle strength and asymmetry percentage

Figure 2. CMJ test to find out the jump height

Statistical Analysis

The data were analyzed using a descriptive test to determine the mean and standard deviation of the asymmetry and jump height values before and after unilateral exercise. Because the number of samples was ≤ 30, the results of the normality test using the Kolmogorov-Smirnov test yielded a sig value of ≤ 0.05, which assumed the data were not normally distributed, the non-parametric Wilcoxon test was performed with a significance level of 5%. The Wilcoxon test was used to compare the initial test results before being given unilateral hamstring muscle strengthening exercises with the final test results after being given unilateral hamstring muscle strengthening exercises for ten weeks. Unilateral hamstring muscle strengthening exercises were declared to have an effect if the Wilcoxon test results stated a value of $p \leq 0.05$. Evaluation of effect size using Cohen's d (Wiriawan et al., 2024). Data analysis was performed using Microsoft Excel 2013 and SPSS 23 version software.

Results

This research was conducted on a sample of 23 people who have male sex characteristics with an age range of 16-20 years and have experience practising badminton for more than five years with the sub-elite athlete category in East Java, Indonesia. The results of a descriptive test of the characteristics of the study subjects are described in Table 2.

Table 2.
Description of characteristics subjects studies

Parameters	mean±SD (n=23)
Age, years	17.61±1.16
Weight, kg	63.57±3.04
Height, cm	168.17±3.31
BMI, kg/m^2	22.48±0.89
Experience in badminton training, years	8.04±1.07

The results of the mean and standard deviation (SD) of the asymmetry and jump height variables can be seen in Table 3

Table 3.
Unilateral hamstring muscle strengthening exercise program

No	Name	Pretest (n=23)		Posttest (n=23)	
		Asymmetry (%)	Jump Height (Cm)	Asymmetry (%)	Jump Height (Cm)
1	AESM	22.60	31.90	10.30	38.60
2	ASDD	13.90	40.20	9.50	42.40
3	AJCJ	16.50	40.20	11.40	41.20
4	DAPD	17.10	38.30	12.10	39.10
5	GR	18.80	33.90	9.70	35.10
6	MIR	14.30	36.80	8.10	38.70
7	AF	17.60	26.70	9.40	30.10
8	BAH	16.30	30.50	10.20	32.30
9	CT	19.50	35.00	12.10	37.10
10	EAM	17.60	31.90	10.40	32.80
11	GFT	16.30	31.40	10.40	33.10
12	JD	13.00	32.60	8.80	35.40
13	MH	22.90	43.10	9.60	42.80
14	MAR	18.20	31.40	11.30	33.50
15	NG	17.60	31.00	13.60	33.20
16	RE	59.80	30.60	17.80	33.40
17	MK	13.90	32.60	6.40	35.60
18	VM	15.10	31.30	4.50	35.9
19	APC	27.18	30.30	3.60	33.8
20	MAA	19.18	23.50	9.70	30.90
21	RAE	38.85	39.00	4.50	37.20
22	MWS	16.44	34.20	6.30	32.60
23	SMR	13.40	24.00	1.90	23.40
	Mean	20.26	33.06	9.20	35.17
	SD	10.25	4.93	3.51	4.54

From a total of 41 samples that were tested for hamstring asymmetry and jump height, it was found that 23 athletes had >10% hamstring asymmetry. This condition is quite dangerous because excessive imbalance can result in less than optimal physical agility and leg power performance and can result in future injuries (Bishop et al., 2018; Paterno and Ford, 2010). Twenty-three athletes who experienced hamstring asymmetry > 10% (Phukan *et al.*, 2021) were given hamstring muscle strengthening exercises using the unilateral training method for 30 meetings for ten weeks. The posttest results showed a decrease in the average asymmetry with an average difference of 11.06% and an increase in the average jump height with an average difference of 2.08 cm from the 23 samples measured.

Unilateral exercises as a treatment in this study were carried out with two models, namely the Swiss ball hamstring curl exercise and the single leg bridge. After ten weeks of treatment, a final test was conducted to determine the effect of asymmetry and jump height. The results are presented in Table 4.

Table 4 above shows the results that significantly influence the results of unilateral exercise for 10 weeks on asymmetry and jump height $p<0.05$.

Table 4.
Effect of hamstring asymmetry and jump height after unilateral exercise

Measurement system	Variable	Assessment	Mean±SD	p-Value	Effect size
Norbord test	Hamstring Asimetry (%)	Pretest	20.26±10.25	0.000	1.443
		Posttest	9.20±3.51		
Counter Movement Jump with Force Plate	Jump height (cm)	Pretest	33.06±4.93	0.000	0.447
		Posttest	35.17±4.54		

Description: p ≤ 0.001 Significantly different using the Wilcoxon test.

Discussion

Several studies state that athletes with asymmetrical leg conditions can increase the risk of injury, and skeletal muscle disorders, reduce their sports performance and limit their movements (Bishop et al., 2018; Tucker and Hanley, 2017). Hoffman et al., (2007) stated in their research that an asymmetry of more than 10% could reduce the agility performance of athletes (Hoffman *et al.*, 2007). Meanwhile, Bell et al., (2014) also in their research stated that an asymmetry of more than 10% could reduce jumping performance (Bell *et al.*, 2014). Sports training is often given as a therapy to improve the athlete's asymmetry, although the improvement is still tiny, and many results are not significant (Bishop, Turner and Read, 2018; Bettariga, Turner, *et al.*, 2022). However, this study has proven that giving unilateral exercises with single-leg bridge movements and Swiss ball Hamstring curls for ten weeks can significantly improve the percentage of hamstring asymmetry. This is in line with the research of Mrzygłód et al., (2021), who stated in their research that soccer training in one season supplemented by a 3-week body weight training program succeeded in reducing gluteal and hamstring imbalances between the legs (Mrzygłód *et al.*, 2021). Studies on soccer players have shown differences in strength and flexibility between dominant and non-dominant limbs in sports movements, giving rise to asymmetry that can cause thigh muscle injuries (Scilingo *et al.*, 2005; Croisier *et al.*, 2008).

The unilateral exercise with the single-leg bridge activates the high hamstrings and gluteals. The knee that bends in the single-leg bridge is considered the dominant hamstring. However, the weakness of the gluteus maximus and medius in high hamstring activation may reduce these exercises' contribution to gluteal strengthening (Lehecka *et al.*, 2017; Pori *et al.*, 2021). In addition, there is a functional-anatomical relationship between the hamstring muscles and the sacrotuberous ligament which also impacts trunk stability (Vleeming, Stoeckart and Snijders, 1989). Then in elite soccer players, it is known that hamstring muscle strengthening exercises can affect explosive activities such as short sprint times of 5 m and 10 m and the results of countermovement jumps. This shows that hamstring muscle-strengthening exercises can positively affect other physical performance (Krommes *et al.*, 2017). The Swiss ball Hamstring curl exercise can increase hamstring muscle strength (Monajati *et al.*, 2017; Guruhan *et al.*, 2020). Hamstring and quadriceps muscle strength measured during maximal isometric or isokinetic contractions is usually reported as the limb symmetry index (LSI) (Undheim *et al.*, 2015; Grindem *et al.*, 2016). The Swiss ball Hamstring curl exercise activates the hamstring muscles, including the biceps femoris and semitendinosus, when in an open knee position (Monajati *et al.*, 2017).

This study also stated that jump performance, as expressed by jump height, had increased after doing unilateral hamstring exercises for ten weeks. These results are consistent with research by Bettariga, Maestroni, et al., (2022), which states that unilateral strength and power training in soccer athletes for six weeks can improve jumping and agility results (Bettariga, Maestroni, *et al.*, 2022). Pardos-Mainer et al., (2020) demonstrated improvement in asymmetry by increasing horizontal jump results by providing female soccer athletes with Nordics, lunges, plyometric and plank exercises for ten weeks (Pardos-Mainer *et al.*, 2020). This shows that the selected strengthening exercises can improve vertical and horizontal jumps (Fitzpatrick, Cimadoro and Cleather, 2019; Arede *et al.*, 2022).

Unilateral strength training can increase jumping performance compared to bilateral training (Liao *et al.*, 2022). Several studies by Bogdanis et al., (2019); Makaruk et al., (2011); Stern et al., (2020) also stated that unilateral training was more effective in increasing jumping performance (Makaruk *et al.*, 2011; Bogdanis *et al.*, 2019; Stern *et al.*, 2020). This is because unilateral training can increase muscle strength more than bilateral exercises (Gonzalo-Skok, Tous-Fajardo, Suarez-Arrones, *et al.*, 2017). This also relates to the principle of specific training (Liao *et al.*, 2022). The specific training principle is crucial for specific adaptation to the planned performance improvement targets (Brearley and Bishop, 2019). By the subjects in this study who used badminton athletes, it is known that badminton is a sport that uses one dominant hand used to hit the shuttlecock, which will be followed by one leg movement by shifting lower leg activity from the ipsilateral leg to the contralateral leg faster while increasing the rate of increase in contralateral leg muscle activity (Masu and Nagai, 2016).

Unilateral exercises can improve lower limb stability and effectively improve unilateral squat jump performance and RFD0–50 ms and RFD0–100 ms (strength development rate) in unilateral isometric seated leg extension (Kulas, Windley and Schmitz, 2005; Bogdanis *et al.*, 2019). Electromyographic results of vertical jumps unilaterally are 10-25% higher than bilaterally seen from the vastus intermedius and gastrocnemius muscles (Turki *et al.*, 2011). Unilateral training increases strength and strongly stimulates muscles such as the ankle, knee and hip extensors to produce greater neuromuscular adaptation (Gonzalo-Skok, Tous-Fajardo, Valero-Campo, *et al.*, 2017). This follows the concept of Andersen et al., (2014), who showed a significant increase in unilateral jump height after an 8-week bilateral and unilateral combined strength training program (Andersen *et al.*, 2014).

The ability to jump is regulated and controlled by the central nervous system through coordination of body joints, muscles, and ligaments to achieve optimal explosive force in the lower limb muscle groups, resulting in the most effective jumping technique (Zhang *et al.*, 2023). Unilateral training and bilateral training, following the specific training principle, enhance neuromuscular control for unilateral and bilateral movements, respectively. This is achieved by increasing the recruitment of motor units, the frequency of nerve impulses, and coordination, thereby improving movement performance. Training one limb at a time can clearly affect the neuromuscular adaptation of that specific limb. Bilateral training had beneficial benefits on bilateral motions (Gadea Uribarri *et al.*, 2023). Unilateral training leads to an increase in muscle strength and neural activity on the untrained side, known as the cross-migration effect (Howatson *et al.*, 2013). This increase in strength is linked to a rise in EMG activity, indicating that central neural adaptation plays a crucial role in strength development. The precise process of cross-migration is not fully understood; however, theories suggest it could be linked to brain adaptation, intricate alterations in contralateral motor pathways, and motor learning as postulated (Lee and Carroll, 2007). During cross-migration, there is no notable enlargement in the cross-sectional area of the corresponding muscle on the opposite side. This phenomenon seems to be linked to the adjustment and control of the neuromuscular system by the cerebral cortex and spinal cord, with minimal impact from myogenic factors (Bezerra *et al.*, 2009). There is a strong relationship between motor cortex activity and the impact of training. Unilateral training can improve bilateral muscle strength and potentially decrease inhibitory signals from the trained side to the untrained side of the nervous system. Cross-migration is primarily based on neuromodulation of the brain and spinal cord. Unilateral training triggers activity in the central nerve on the non-training side, which is then transmitted to the motor cortical area on the training side through a conduction pathway. Meanwhile, the motor cortical area on the non-training side is somewhat suppressed. The signal is then sent via the corticospinal tract to the motor neurons in the anterior horn of the spinal cord, leading to sustained excitement in the spinal motor neurons and influencing muscle contraction (Zhang *et al.*, 2023).

Conclusions

Unilateral exercise with two models, namely the Swiss ball hamstring curl exercise and the single leg bridge for ten weeks, can improve hamstring asymmetry, the percentage of which is above 10%. In addition, this unilateral exercise can also increase jumping performance which is expressed in jump height. This study recommends doing hamstring muscle strengthening exercises with a unilateral method so that the risk of high asymmetry is reduced and the possibility of injury to the hamstring and other muscles around the knee is reduced.

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Conflicts of Interest

The authors declare no conflict of interest.

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