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ORIGINAL

Effects of an 8-week Pilates Core Training on the Stability and Symmetry of the L-sit on Rings

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Objective: Gymnastics on rings needs a high level of muscle strength with balance ability for controlling the body. A study on a new balance training program is necessary for elite gymnasts. Therefore, the purpose of this study was to investigate the effects of an 8-week pilates core-muscle training on balance ability and asymmetry index of the L-sit on the rings in male elite gymnasts.

Method: Ten elite gymnasts (age: 20.6±0.7 years, height: 169.9±4.9 cm, weight: 65.4±5.6 kg, career duration: 20.6±0.7 years), who are students at K-university, participated in this study.

Results: First, the range of the COM tended to decrease in the anterior-posterior direction. Second, the left hip joint angle and knee extension and ankle dorsiflexion angles significantly increased after the pilates training. Third, the ROM also increased. Fourth, the symmetry value increased in the hip angle, while the symmetry index in all joints of the ROM decreased. As a result, the pilates core-muscle training influenced the static balance ability during the L-sit on the rings.

Conclusion: Accordingly, the pilates core-muscle training is suitable in enhancing the basic balance ability in gymnastics on rings.

Keywords: Gymnastics, Rings, L-sit, Perturbation, Symmetry

INTRODUCTION

The ring is a gymnastic event where participants compete with their expressive abilities and techniques 260 cm above the mat, suspended by two rings hung on ropes (Kim & Nam, 2015). The technical criteria encompass shaking, strength techniques, and holding (Federation of International Gymnastics [FIG], 2013). Since the techniques are performed while holding on to rings, they require more strength than other events (Back, Park, & Lee, 2006; Bernasconi, Tordi, Paratte, & Rouillon, 2004; Dunlavy et al., 2007).

The rings can be divided into five groups based on the acting elements. Group I encompasses rising and swing motions (including L-sit); group II encompasses handstand motions (2 sec); group III encompasses rising and holding (L-sit not included; hold for 2 sec); group IV encompasses holding with muscle strength (2 sec); and group V encompasses descending motions. Ring events must display one technique from the five element groups described above (FIG, 2013) and require a stable static balance since most transitions between dynamic techniques require holding with muscle strength (Han & Jeong, 2012; Omorczyk, Kost, Dudek, Bujas, & Nosiadek, 2013). L-sit is the most basic movement that evaluates static balance (Sommer, 2008) and is a strength technique that connects to other successive techniques (Straddled L-sit, Uprise fwd to L-sit, Any-cross, Backward swing to L-sit, Kip to L-sit, Uprise bwd, to straddled L-sit, From cross, press to L-sit) (FIG, 2013).

A study by Uzunov (2012) described L-sit as an essential technique that should be mastered before advancing to more difficult movements, such as handstand and pike. A study by Sommer (2008) stated that in order to overcome the instability of the ropes during L-sits, co-operation between flat back, chest up, locked elbow, hip forward, and leg hold should be improved.

The scoring criteria of the FIG (2013) state that L-sit is a low-difficulty (A, B, C) technique compared to the highest-leveled technique at F (0.6). However, high-level techniques, such as L-cross and V-sit (D, E) require L-sit as initiation; therefore, L-sit is directly related to balance evaluation. Further, it has been reported that L-sit requires the most practice time since it is a basic technique that determines the level of perfection of a routine (Sommer, 2008). Therefore, technical analysis of L-sit should be conducted for successful completion of a routine.

Previous studies on the rings to date have conducted electromyography (EMG). A study by Yoon (1997) reported that effective training methods could be developed by analyzing EMG data, while that by Kim (1985) reported that the muscle activities of the upper limbs were higher while performing an iron cross. Further, another study by Kim (2001), which analyzed EMG data while the participants performed an inverted iron cross, reported that the highest upper limb muscle activities were observed in the biceps followed by the triceps. A study by Park (2004) reported that during swallow, back muscle activities were the highest in the erector spinae followed by the pectoralis major, palmaris longus, triceps, deltoid, latissimus dorsi, and trapezius. Considering the different muscle distributions, the activity of the pectoralis major should be increased in order to improve stability.

Previous studies were mostly fragmental studies where only muscle activities in different positions, order of muscle activation, and location of the muscle activities were identified. Therefore, development of a training program that could influence the actual performance has been limited.

A recent study by Jason (2011) reported that the constant holding of the swaying body on rings could be a solution since the capacity of the complex core muscles is increased.

Although several core training methods have been used by elite gymnasts (Basset & Leach, 2011; Hibbs, Thompson, French, Wrigley, & Spears, 2008; Kim & Lee, 2010; McGil, 2010; Verschueren, Roelants, Delecluse, Swinnen, Vanderschueren, & Boonen, 2004; Wang & Li, 2007), most of them were intended for rehabilitation of the athletes after accidents and not intended solely to improve performance (Hibbs et al., 2008; Kim & Lee, 2010; McGil, 2010). Studies that investigated the stiffness of the muscle during core training (Wang & Li, 2007) and applications of a new training to improve the performance of elite gymnasts are almost non-existent. Recently, pilates has gained attention as an equipment-using core training method (Critchley, Pierson, & Battersby, 2011; Culligan et al., 2010; Emery, De Serres, McMillan, & Cote, 2010; Irez, Ozdemir, Evin, Irez, & Korkusuz, 2011; Kloubec, 2010; Park & Kim, 2007). Pilates is a regulatory exercise (contrology) developed for a neutral spine. Pilates develops the core muscles, such as the spinal erector muscle, transversus abdominis, and internal oblique to stabilize the spine and regulates the pelvis and hip (Phrompaet, Paungmali, Pirunsan, & Sitilertpisan, 2011).

Since pilates is based on static movements, such as balancing, focusing, regulation of movements, precision, respiration, and flow (Herrington & Davies, 2005; Johnson, Larsen, Ozawa, Wilson, & Kennedy, 2007; McMillan, Proteau, & Lebe, 1998; Sekendiz, Altun, Korkusuz, & Akin, 2007), it can be inferred that pilates would be an effective training method for the rings, which require strength holding and static balance.

Therefore, in this study, an 8-week pilates core training was applied, and the kinetic changes while performing the L-sit were analyzed. The analysis will be then used to evaluate the effectiveness of pilates as a balance-improving training program for elite gymnasts.

METHODS

1. Subjects

This study was conducted on 10 gymnasts from K University. The control group was composed of five gymnasts receiving existing trainings, and the training group was composed of five gymnasts who have received the 8-week pilates training. The participants' characteristics are shown in (Table 1).

Table 1. Research participants

Group (n)	Age (years)	Height (cm)	Weight (kg)	Career duration (years)
Control group (5)	21.8±0.8	167.4±4.6	63.4±4.4	11.6±1.5
Training group (5)	21.4±0.5	172.4±4.0	67.4±6.5	11.8±1.8

Table 2. Pilates core training program

Exercise	Times
Abdominal curls - Feet on the floor - Legs in the chair position - Legs straight, ring between the legs	8
Oblique abdominals - Criss cross - Oblique reach (abdominals with the ring between the legs)	8
Hip lift - Head down - Head up	6
Roll up	6
Roll over	6
The hundred - Knees bent - Lift the upper body & lower the legs	5
Bridge - Marching, bridge position lift one leg off the mat - Ridge position, one leg on the ring	6
Rolling like a ball	10
Open leg rocker	6
Teaser series - Teaser #1 - Teaser #2 - Teaser #3	4
Side leg series (both sides) - Leg lifts, advanced position - Leg circles, advanced position - Bananas, lift bottom arm & ring squeeze	8
Jackknife	6
Opposite arm and leg reach 3	4
Leg pull down	6
Leg pull up	6
Kneeling side kicks (each side)	6
Kneeling side circles (each side)	6
Side bend twist (each side)	4
Side bend mermaid (each side)	4

Figure 1. Pilates core training.

2. Training program

The pilates training program used in this study was developed by both a current pilates instructor and a gymnastics instructor from K University to take into account the gymnasts' abilities. The trainings were conducted regularly two times a week for one hour per session while both instructors were present. The components of the pilates training program are shown in (Table 2) & (Figure 1).

3. Procedure

This study was conducted by performing L-sits on the ring before and after pilates core training, and the balance was evaluated while the participants performed 2 sec of the L-sit movement. The completion level of the L-sit was confirmed by the gymnastics referee from K University (Licensed referee). In order to record the movement, reflect markers were placed on the joints (four on the upper limb and four on the lower limb) and on the ring (two on each ring). Eight infrared cameras (Oqus 500, Qualisys, SWE) were used to record and collect data. The sampling rate of the cameras was set to 100 Hz, and the extracted 3D coordinates were processed with the Buterworth 2nd order low-pass filter to reduce the noise. The cut-off frequency was set to 6 Hz.

4. Data analysis

The balance ability while maintaining the L-sit hold was analyzed using the Qualisys Track manager software (Qualisys, SWE) and Matlab R2009b software (The Mathworks, USA). For body modeling, 16 markers were placed on the joints, and kinetic data were calculated. The completion level of the L-sit hold was determined using the FIG (2013) for the scoring criteria, which state that the lower limbs should be horizontal while the gymnast is on the rings and have to hold the position for 2 sec. If there is a deviation in the angle (<15°, 16~30°, >45°), the hand, foot, or body is adjusted, or if the ring rope is shaken vigorously, the hold was deemed as invalid by the FIG article 22. The hold was inspected by a referee and was approved if it did not violate any of the

Figure 2. Rule of the L-sit.

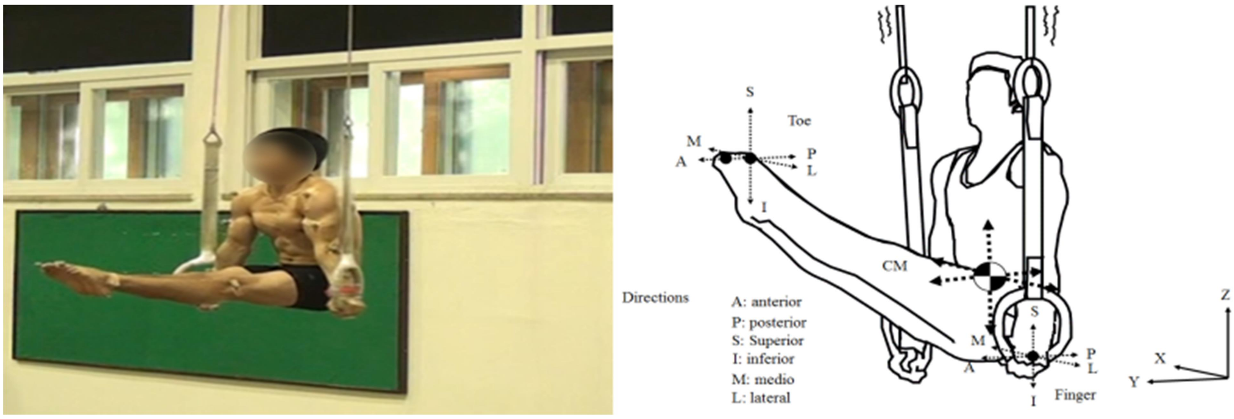

Figure 3. L-sit posture.

criteria listed above (Figure 2). For adjustments to the testing environment, three trials were conducted, and the most stable trial was confirmed by the referee and the data from the most stable trial were analyzed.

5. Analysis variables

To investigate the effects of the pilates core training on the L-sit hold in elite gymnasts, the average kinetic variables and their standard deviations and the symmetry index (SI) of L-sit, as shown in (Figure 3), were analyzed.

1) Displacement

The magnitude of shaking and the changes in trajectory of the center of mass (COM) movement (FIG, 2003), which are factors for deduction, were confirmed by analyzing each variable's anterior-posterior, mediolateral, and superior-inferior changes.

- COM
- Finger position
- Toe position

2) Angle & range of motion (ROM)

In order to analyze the changes in the gymnast's position while restricting shaking and movement, the angle and ROM of the lower limb joints were defined (Figure 4) and analyzed.

- Hip joint angle
- Knee joint angle
- Ankle joint angle

3) SI

A previous study that used the symmetry analyzing method (Kim & Eng, 2003; Robinson, Herzog, & Nigg, 1987) calculated the bilateral lower limb joint angle and ROM SI. An SI close to 0% indicates symmetry and could range up to 200% (Yoo et al., 2014).

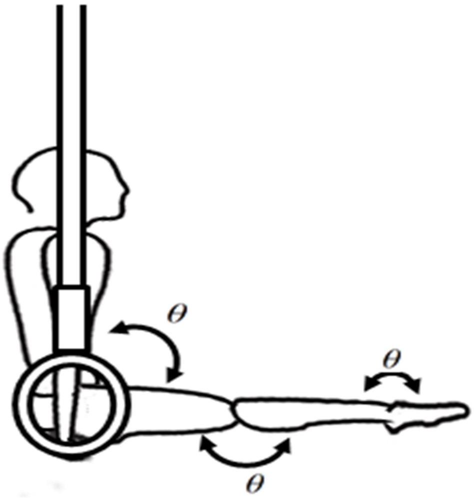

Figure 4. Define angles.

$$\mathrm{SI} = \frac{|X_R - X_L|}{\frac{1}{2}(X_R + X_L)} \times 100$$

X_R = Right foot variable, X_L = Left foot variable

6. Statistical analysis

In order to investigate the changes between the groups and before and after pilates training, a two-way repeated measure analysis of variance was conducted. The significance level was set to α=.05.

RESULTS

To investigate the effects of the 8-week pilates core training on balance during the L-sit hold, the ROM of the COM during the movement, ROM of the distal hands and feet, angles and ROM of the lower limb joints, and SI were measured. The measurements are shown below.

1. ROM of the body

Although no significant changes in the COM were observed in the anterior-posterior, medio-lateral, and superior-inferior directions, the control group showed an increase in the medio-lateral direction from 5.03±3.46 cm to 6.16±3.38 cm, while the experimental group showed a decrease in the medio-lateral direction from 4.96±3.32 cm to 3.38±0.91 cm (Table 3). The ROMs of the right distal hand and foot in the superior-inferior direction increased from 4.39±1.08 cm to 7.17±2.77 cm after the training. The ROMs of the right and left distal feet in the medio-lateral direction showed interaction effects of p=.03 for each, which indicates the effects of the training.

Table 3. Oscillation of the motions

Variables	Group	Pre-test	Post-test	F (p)
COM range M-L	CG	5.03±3.46	6.16±3.38	0.04 (0.85)
	TG	4.96±3.32	3.38±0.91	
	F (p)	0.91 (0.37)		1.44 (0.26)
COM range A-P	CG	7.58±3.07	3.37±2.91	3.35 (0.10)
	TG	11.38±7.42	10.02±4.95	
	F (p)	3.68 (0.09)		0.87 (0.38)
COM range S-I	CG	0.88±0.52	1.05±0.62	4.14 (0.08)
	TG	0.89±0.10	1.05±0.33	
	F (p)	0.00 (0.99)		0.01 (0.91)
R Finger M-L	CG	5.27±3.60	6.49±3.64	0.23 (0.65)
	TG	5.96±3.84	5.94±1.88	
	F (p)	0.00 (0.97)		0.24 (0.64)
R Finger A-P	CG	10.61±3.24	7.09±2.26	1.67 (0.23)
	TG	13.32±7.93	113.45±6.09	
	F (p)	1.78 (0.22)		0.07 (0.80)
R Finger S-I	CG	3.86±0.66	5.96±2.63	10.38 (0.01)
	TG	4.39±1.08	7.17±2.77*	
	F (p)	0.73 (0.42)		0.20 (0.67)
L Finger M-L	CG	7.14±3.99	8.78±3.95	0.40 (0.54)
	TG	7.51±4.10	3.90±1.71	
	F (p)	1.86 (0.21)		2.85 (0.13)
L Finger A-P	CG	10.05±2.53	5.22±3.25	2.51 (0.15)
	TG	14.42±7.96	14.05±5.90	
	F (p)	4.93 (0.06)		1.83 (0.21)
L Finger S-I	CG	5.44±4.68	3.46±2.51	0.16 (0.70)
	TG	4.07±2.11	6.82±4.78	
	F (p)	0.21 (0.66)		6.05 (0.04)

Table 3. Oscillation of the motions (Continued)

Variables	Group	Pre-test	Post-test	F (p)
R toe M-L	CG	5.96±3.81	9.15±4.12	0.04 (0.84)
	TG	7.80±4.07	5.07±3.57	
	F (p)	0.26 (0.62)		7.02 (0.03)
R toe A-P	CG	8.62±3.61	4.26±3.17	2.77 (0.13)
	TG	11.20±8.06	9.55±5.10	
	F (p)	1.90 (0.21)		0.56 (0.47)
R toe S-I	CG	5.47±06.58	8.36±4.72	3.39 (0.10)
	TG	5.50±1.93	6.88±08.86	
	F (p)	0.38 (0.56)		0.43 (0.53)
L toe M-L	CG	6.05±3.73	9.12±4.11	0.04 (0.85)
	TG	7.90±4.10	5.28±3.39	
	F (p)	0.21 (0.66)		6.53 (0.03)
L toe A-P	CG	8.50±3.61	4.27±3.21	3.00 (0.12)
	TG	11.61±8.04	10.03±5.51	
	F (p)	2.19 (0.18)		0.62 (0.45)
L toe S-I	CG	5.53±0.89	8.16±4.77	3.33 (0.11)
	TG	5.46±1.72	7.12±0.89	
	F (p)	0.23 (0.65)		0.17 (0.69)

COM: center of mass, R: right, L: left, M: medio, L: lateral, A: anterior, P: posterior, S: superior, I: inferior
*: significant difference between pre-training and post-training at p<.05

2. Lower limb joint angles

The left hip joint while performing the L-sit hold increased from 62.89±4.46° to 67.50±8.97° in the control group after the training, while the hip angle significantly increased from 59.16±5.62° to 68.11±4.56° (p=.01). The changes in the right knee angle were significantly different between the two groups, and the left knee angle showed almost no change from 174.97±2.31° to 174.66±2.93° in the control group. The left knee angle in the experimental group increased from 171.98±2.76° to 178.49±1.42° (p=.01). The results indicate an interaction effect (p=.01), and the effects of the training were confirmed (Table 4). The ankle angles decreased from 141.61±10.95° to 136.86±6.45° in the control group and decreased from 136.06±6.12° to 129.64±6.55° in the experimental group (p=.01).

3. ROM of the lower limb joints

The ROM of the hip, knee, and ankle joints showed an overall increase after the L-sit (Table 5). The ROM of the right knee did not change significantly from 0.74±0.28° to 0.88±0.26° in the control group, while that in the experimental group showed a significant increase from 0.84±0.56° before training to 1.98±0.91° after training (p=.01). Further, it was determined that interaction effects were present after the training (p=.02).

Table 4. Joint angles

Variables	Group	Pre-test	Post-test	F (p)
R Hip	CG	73.63±4.76	73.15±6.18	2.98 (0.12)
	TG	72.93±8.15	67.66±6.31	
	F (p)	0.69 (0.43)		2.08 (0.19)
L hip	CG	62.89±4.46	67.50±8.97	12.60 (0.01)
	TG	59.16±5.62	68.11±4.56*	
	F (p)	0.21 (0.66)		1.29 (0.29)
R knee	CG	176.44±1.14	177.67±1.39	1.81 (0.22)
	TG	173.95±2.2	175.05±3.2	
	F (p)	6.00 (0.04)		0.01 (0.94)
L knee	CG	174.97±2.31	174.66±2.93	11.09 (0.01)
	TG	171.98±2.76	178.49±1.42*	
	F (p)	0.12 (0.74)		13.39 (0.01)
R ankle	CG	141.61±10.95	136.86±6.45	10.23 (0.01)
	TG	136.06±6.12	129.64±6.55*	
	F (p)	1.93 (0.20)		0.23 (0.65)
L ankle	CG	140.35±12.59	134.75±10.67	3.63 (0.09)
	TG	133.36±6.97	131.71±8.32	
	F (p)	0.71 (0.42)		1.07 (0.33)

R: right, L: left
*: significant difference between pre-training and post-training at p<.05

Table 5. Range of motion

Variables	Group	Pre-test	Post-test	F (p)
R Hip	CG	2.81±1.34	3.01±1.94	0.53 (0.49)
	TG	2.35±0.92	3.04±1.09	
	F (p)	0.12 (0.74)		0.16 (0.70)
L hip	CG	2.54±1.14	2.83±1.24	3.02 (0.12)
	TG	2.6±0.98	4.02±1.62	
	F (p)	0.97 (0.35)		1.32 (0.28)
R knee	CG	0.74±0.28	0.88±0.26	12.73 (0.01)
	TG	0.84±0.56	1.98±0.91*	
	F (p)	3.79 (0.09)		7.81 (0.02)
L knee	CG	1.22±0.56	1.90±2.19	1.07 (0.33)
	TG	0.76±0.20	1.35±1.31	
	F (p)	0.81 (0.39)		0.01 (0.94)

Table 5. Range of motion (Continued)

Variables	Group	Pre-test	Post-test	F (p)
R ankle	CG	1.11±0.56	1.77±0.63	4.92 (0.06)
	TG	1.60±0.95	2.18±0.74	
	F (p)	1.45 (0.26)		0.02 (0.89)
L ankle	CG	2.05±1.92	2.74±2.45	0.01 (0.92)
	TG	2.23±1.28	1.71±0.56	
	F (p)	0.45 (0.52)		0.48 (0.51)

R: right, L: left
*: significant difference between pre-training and post-training at p<.05

4. SI

The SI of the ROMs and angles of the bilateral lower limb joints during the L-sit showed that the SI of the hip joint angle decreased from 15.75±5.42% to 11.42±7.9% in the control group (Table 6). The SI in the experimental group decreased significantly from 20.69± 8.68% to 4.24±2.68% (p=.00). It was determined that interaction effects were present after the training (p=.04).

Table 6. Symmetry index of the joint angles

Variables	Group	Pre-test	Post-test	F (p)
Hip	CG	15.75±5.42	11.42±7.9	17.71 (0.00)
	TG	20.69±8.68	4.24±2.68*	
	F (p)	0.11 (0.75)		6.02 (0.04)
Knee	CG	1.4±0.6	1.84±1.05	0.43 (0.53)
	TG	1.94±1.21	2.15±1.37	
	F (p)	0.77 (0.40)		0.05 (0.82)
Ankle	CG	2.58±1.23	2.6±3.38	0.02 (0.89)
	TG	5.53±1.97	5.81±3.23	
	F (p)	5.75 (0.04)		0.02 (0.90)

*: significant difference between pre-training and post-training at p<.05

On the other hand, no significant differences were observed between any of the variables of the knee and the ankle. The SI of the ROMs of the lower limb joints also showed no significant differences bilaterally. Therefore, it can be inferred that the training did not have a significant effect on the SI (Table 7).

DISCUSSION

This study was conducted to investigate the effects of pilates training

Table 7. Symmetry index of the ROM

Variables	Group	Pre-test	Post-test	F (p)
Hip	CG	26.04±15.56	20.64±8.34	1.38 (0.27)
	TG	54.43±27.03	37.64±41.01	
	F (p)	2.81 (0.13)		0.37 (0.56)
Knee	CG	47.75±28.04	58.45±51.4	0.53 (0.49)
	TG	58.61±29.21	69.23±37.1	
	F (p)	0.33 (0.58)		0.00 (1.00)
Ankle	CG	49.29±39.67	63.3±49.42	0.05 (0.83)
	TG	45.89±20.21	38.85±26.77	
	F (p)	0.71 (0.42)		0.46 (0.52)

ROM: range of motion
*: significant difference between pre-training and post-training at $p<.05$

on the static balance during the L-sit, a movement of the gymnastics rings. The displacements, changes in the position of the distal hands and feet, angles and ROMs of the lower limb joints, and SIs were studied as variables of balance evaluation on the rings.

First, the changes in the COM of the body showed that no significant changes were observed in any of the directions. However, the medio-lateral movement increased in the control group (before training: 5.03 ±3.46 cm, after training: 6.16±3.38 cm) while it decreased in the experimental group (before training: 4.96±3.32 cm, after training: 3.38±0.91 cm). Therefore, it can be inferred that the training indirectly affects the medio-lateral movement. Significantly increased distal hand movements in the superior-inferior direction in the experimental group and interaction effects between the distal feet and the medio-lateral direction ($p=.03$) indicate that the pilates training effectively decreases the medio-lateral movement of the COM of the body.

Second, the angle of the left hip joint significantly increased from 59.16±5.62° to 68.11±4.56° after the training in the experimental group ($p=.01$). However, the change was not consistent with that in the right hip joint, where the average angle decreased; therefore, it can be inferred that each hip joint moves in different directions. These findings coincide with the findings in the study by Uzunov (2012), which reported that the hip should face forward and the lower limbs should be straight during the L-sit. The different hip joint movements during the core training can be inferred to be due to motor control (Akuthota & Nadler, 2004), and the hip could have moved to stabilize the COM of the body (McGill, 2010). Further, the reason why the knee angle increased was to effectively transfer force to the COM (Uzunov, 2012). The increase in angle was induced by the weight bearing of the lower limb (Willardson, 2007), and the decrease in ankle angles in both groups indicates that those techniques were performed to maintain the straight extension of the lower limb during the L-sit.

The ROM of the right knee significantly increased from 0.84±0.56° before training to 1.98±0.91° after training in the experimental group ($p=.01$). The ROM of the other joints has overall increased. As stated previously, the changes were caused by the regulatory efforts of the lower limbs. The SI confirmed that the hip joint symmetry improved after the training (before training: 12.22±6.31%, after training: 2.32± 1.38%), which indicates that the training evidently affects the ROM of the joints of the group that received the training ($p=.05$).

Since the ultimate goal of the L-sit is to stabilize posture, it can be inferred that the unstable lower limbs are alternatively regulated by the hip joints. Owing to the characteristic free movement of the rings (all directions freely; Yamada, Watanabe, Kiguchi, & Izumi, 2001), deliberate changes in the lower limb (knees and ankles) during unstable conditions (Plessner & Schallies, 2005) contribute to the stability handling by the hip joint.

Ultimately, it can be inferred that equilibrium and agility, which are crucial for body balance (Chae, Jang, & Woo, 1992; Kim et al., 2007), have been improved by the pilates training.

CONCLUSION

This study was conducted to investigate the effects of an 8-week pilates core training on balance during the L-sit hold. Five participants were selected for the control group and five for the experimental group that received the pilates core training. The ROM of the body, lower limb joint angles, ROM of the lower limb joints, and SI before and after the training were analyzed and compared. The results were as follows:

First, the ROM of the body decreased in the medio-lateral direction. Second, the left hip joint angle increased after the training, while the knee angle increased after the core training and the ankle joint was dorsiflexed. Third, the ROMs of the joints increased after the core training. Fourth, the SI of the hip joint angle and ROMs of all the joints also increased. Therefore, it was determined that pilates core training positively affects the static balance during L-sits and is suitable as a training program that improves the basic balance for the rings.

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