Factors Influencing Pelvic and Trunk Motions During One-Leg Standing

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ABSTRACT

Factors Influencing Pelvic and Trunk Motions During One-Leg Standing

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One-leg standing (OLS) test has been used to assess not only balance ability but also lumbopelvic stability in the clinical field. The purposes of this study were to define the normal motion of the pelvic and trunk motions, to identify their relationship, and to determine the factors that influenced the pelvic and trunk motions during OLS in healthy young subjects. Eighty healthy participants volunteered for this study. Anthropometric data were recorded, and the maximal isometric muscle strength of the hip and trunk were measured with an isokinetic device. The pelvic and trunk motions were measured using a three-dimensional motion analysis system, and muscle activity of hip and abdominal muscles was recorded with surface electromyography (EMG) during OLS. Pearson correlation was used to identify correlation between the pelvic and trunk motions. Stepwise multiple regression was used to find the predictor variables that affected pelvic and trunk motions during OLS.

There were significant correlations between the pelvic and trunk motions during OLS. Factors influencing the pelvic lateral shift were the foot length, the ratio of the hip abductor/adductor strength in the stance side, and the external oblique activity in the lift side (R^2=0.22). The tensor fasciae latae (TFL) length in the stance side and the ratio of the hip external/internal rotator strength of the stance side were factors found to have a significant influence on pelvic rotation (R^2=0.18). Factors influencing the trunk lateral shift were gluteus medius activity in the stance side, the external oblique activity in the lift side, the foot length, and the ratio of the hip abductor/adductor strength in the stance side (R^2=0.27). The TFL length in the stance side was the only factor found to have a significant direct influence on trunk rotation (R^2=0.14).

This study indicates that both pelvic and trunk motions should be considered during the OLS test as a determinant of movement dysfunction in lumbopelvic stability. Additionally, this study suggests that the muscle activity of the external oblique and gluteus medius, the ratio of hip abductors/adductors strength, and the ratio of hip external/internal strength, and the length of TFL should all be included in both the evaluation and treatment of lumbopelvic stability.

Key Words: Lumbopelvic stability, One-Leg Standing, Postural Control.

Introduction

Postural control is defined as the effective maintenance and movement of the body to efficiently carry out a skilled task. Static postural control, automatic or reactive postural responses, anticipatory postural responses, and volitional postural movements are essential for postural control (Allison, and Fuller 2001; Shumway-Cook, and Woollacott 2001). The active alignment of the body to sensory information, gravity, vestibular and visual systems, ground state, inner references, and the surrounding environment all influence effective postural control (Horak 2006).

Reduced automatic postural reactions, lumbopelvic instability (Hungerford, Gilleard, and Hodges 2003), and diminished strength of the trunk or the lower extremity muscles have been reported to decrease postural control (Szklut, and Breath 2001). The ability to maintain a one-leg standing (OLS) position is required for many everyday activities (Jonsson, Seiger, and Hirschfeld 2004) and the OLS test has been used to evaluate the static balancing ability of elderly subjects (Allison, and Fuller 2001; Berg et al. 1992; Bohannon, and Leary 1995; Bohannon et al. 1984; Michikawa et al. 2009). Additionally, the OLS test has been used to assess both lumbopelvic stability and quality of movement (Fritz, and George 2000; Janda, and Va'vrova 1996; Liebenson 2005; Luomajoki et al. 2007; 2008; Millisdotter, Stromqvist, and Jonsson 2003; O'Sullivan 2000; Roussel et al. 2007; Sahrmann 2002;

Tidstrand, and Horneij 2009). The OLS was developed to assess qualitatively the lumopelvic stability by Janda (Janda, and Va'vrova 1996; Liebenson 2005) and the OLS is performed with hip flexion in the standing position with both feet in close proximity. This differs from previous authors who describe the angle of the hip flexion as 45° (Liebenson 2001), 60° (Janda, and Va'vrova 1996; Liebenson 2005; 2007; Tidstrand, and Horneij 2009), or 70° (Sahrmann 2002). Additionally, for sacroiliac stability, a hip flexion angle of 90° was favored (Hungerford, Gilleard, and Hodges 2003; Jacob, and Kissling 1995).

Janda stated that a pelvic side shift of less than one inch occurred in the absence of a pelvic lateral tilt during the OLS test in healthy subjects (Janda, and Va'vrova 1996). Tidstrand and Horneij (2009) demonstrated that the OLS test was a reliable measure of lumbar instability and described negative and positive test results for OLS, following visual inspection, photography, and video recordings. For negative OLS tests, a spine line in a vertical position, the pelvic crests in a horizontal plane, and/or no compensatory movement for muscular functional coordination of the lumbar spine were reported. For positive tests, they stated that spinal deviation, pelvic crest deviation, or compensatory movement at least two short changes from the starting position occurred. Luomajoki and colleague (2007) used OLS for movements of control dysfunction tests of the lumbar spine, whereby a plastic triangular ruler was used to measure the lateral shift of the umbilicus between the bipedal standing position and the OLS position. They described a greater than 2 ㎝ lateral shift difference between both sides of the umbilicus motion and a more than 10 ㎝ lateral shift of umbilical motion as incorrect performance. Other researchers used OLS tests to measure isometric strength in the hip abductor of the standing leg and focused the pelvis in a horizontal plane and the center of the gravity shift or the compensatory movements with the free extremities (Millisdotter, Stromqvist, and Jonsson 2003). Sahrmann (2002) used the OLS test for the classification of lower back pain related to rotation components. A positive OLS test occurs if a rotation of the lumbar or pelvis, or hip drop occurs.

Roussel and colleagues (2007) reported favorable test-retest reliability of the OLS test in analyzing the motor control mechanisms of the lumbopelvic region in non-specific lower back patients. Other authors suggested that the normal lateral shifting to the stance leg should not be more than 1 inch and should be performed for 15-20 s with no compensatory movement (Janda, and Va'vrova 1996; Liebenson 2005; 2007). Additionally, Hungerford and colleagues (2003) used the OLS test to screen for pain in the sacroiliac joint.

Lumbopelvic stability is controlled by three subsystems. The passive stabilizing system is achieved both by osseo-ligaments and capsules in the spinal column, active spinal muscles and neural control subsystems that provide dynamic stability and co-ordination (Panjabi 2003). Three muscle slings, the longitudinal (multifidus and long head of biceps femoris), posterior oblique (latissimus dorsi and gluteus maximus), and anterior oblique sling (external oblique, internal oblique, and transversus abdominis) contribute to lumbopelvic stability (Pool-Goudzwaard et al. 1998; Snijders et al. 1998; Vleeming et al. 1995). The stability of inter-segmental lumbopelvic motion is preserved by various central nervous system strategies that control and modulate the muscle recruitment pattern and timing (Hungerford, Gilleard, and Hodges 2003). Although the active muscle subsystem plays a critical role in the control of lumbopelvic stability, to our knowledge, there has been no previously reported study demonstrating a relationship between muscle activity of the abdominal and hip muscles, and pelvic and trunk motions during the OLS test. The OLS test has been used to determine the isometric strength in the hip abductor of the standing leg (Millisdotter, Stromqvist, and Jonsson 2003); however, no relationship between proximal musculature (abdominal and hip) strength and the pelvic and trunk motions was described.

A few studies have suggested that the shortness of the tensor fasciae latae (TFL) contributes to pelvic rotation during the stance phase (Hudson, and Darthuy 2009; Sahrmann 2002) and the majority of these studies were performed with respect to the patellofemoral pain syndrome (Reese, and Bandy 2003). Thus, the exact role of the length of TFL remains unknown in the OLS test. Hardcastle and Nade (1985) observed different movement patterns with the OLS test: the pelvic hike on the non-stance side, parallel pelvis, and pelvic drop on the non-stance side when moving the torso and the center of gravity over to the stance side. O'Sullivan (2000) suggested that the inability to activate the local lumbar multifidus and the lack of co-contraction with the transversus abdominis are possible causes of the lateral shift of the trunk, rather than the pelvic shift observed with the OLS test.

Previous reports have used the OLS test for different purposes with various qualitative (visual judgment such as pelvic drop, shift, and rotation and trunk shift, and palpation of posterior superior iliac spine) and different criteria for quantitative grading systems (pelvic shift of less than 1 inch, lateral shift of umbilicus less than 10 ㎝); however, it is unclear how the results of the OLS test should be interpreted. Furthermore, few studies have investigated muscle activity while maintaining the OLS or the effects of muscle length and the ratio of muscle strength on the performance of the OLS. The purposes of this study were to define the normal motion of the pelvic and trunk motions, to identify their relationship, and to determine the factors that influenced the pelvic and trunk motions during OLS in healthy young subjects.

Method

1. Subjects

Eighty healthy participants (forty-two men and thirty-eight women) volunteered for this study. The subjects were college students in the Daegu city and the purpose of the study was carefully explained to each subject; each signed an informed consent form. This study was approved by the institutional review board in the Yonsei University (Wonju Medical College).

Subjects were excluded if they displayed a history of lower back pain in the previous year, sacroiliac joint pain, balance impairment, foot pain, deformities, acute trauma, surgery of the lower extremities or back, leg length discrepancies, diabetes mellitus, peripheral neuropathy, or vascular insufficiency. The Gillet test was used to rule out sacroiliac joint pain (Strok test) (Hungerford, Gilleard, and Hodges 2003; Jacob, and Kissling 1995) and the OLS test with one eye closed for up to 30 seconds was used to identify balance impairment (Bohannon et al. 1984; Liebenson 2005). Leg dominance was determined by asking the subject to kick a ball; the kicking leg was selected as the dominant leg (Van Deun et al. 2007).

General characteristics of the subjects were shown in Table 1. All parameters excluding age were normally distributed by the Kolmogorov-Smirnov test. The flow chart for this experimental design was shown in Figure 1.

Table 1. General characteristics of the subjects (N=80)

Parameter		All	Men (n_1=42)	Women (n_2=38)
Age (yrs)		22.45 ± 2.50[a]	22.79 ± 2.20	22.08 ± 2.76
Height (㎝)		169.78 ± 7.09	174.95 ± 5.45	164.05 ± 3.24
Weight (㎏)		61.03 ± 9.02	67.38 ± 7.38	54.03 ± 4.19
Foot width (㎝)		9.37 ± 0.73	9.78 ± 0.62	8.91 ± 0.55
Foot length (㎝)		23.98 ± 1.03	24.62 ± 0.85	23.26 ± 0.70
Pelvic width (㎝)		32.94 ± 1.61	33.40 ± 1.27	32.44 ± 1.80
TFL[b] length (°)	Dominant	9.08 ± 8.04	8.89 ± 7.20	7.62 ± 8.67
	Non-dominant	9.95 ± 4.80	11.23 ± 6.93	9.03 ± 6.27
ROM of hip ER[c] (°)	Dominant	44.23 ± 10.58	43.05 ± 8.64	44.46 ± 9.00
	Non-dominant	44.75 ± 11.89	42.50 ± 4.04	46.17 ± 8.10
ROM of hip IR[d] (°)	Dominant	40.13 ± 1.68	35.55 ± 9.98	44.19 ± 9.08
	Non-dominant	39.63 ± 9.63	38.50 ± 4.04	43.50 ± 8.44

[a]Mean ± SD.
[b]TFL: Tensor Fasiae Latae.
[c]ER: External Rotation.
[d]IR: Internal Rotation.

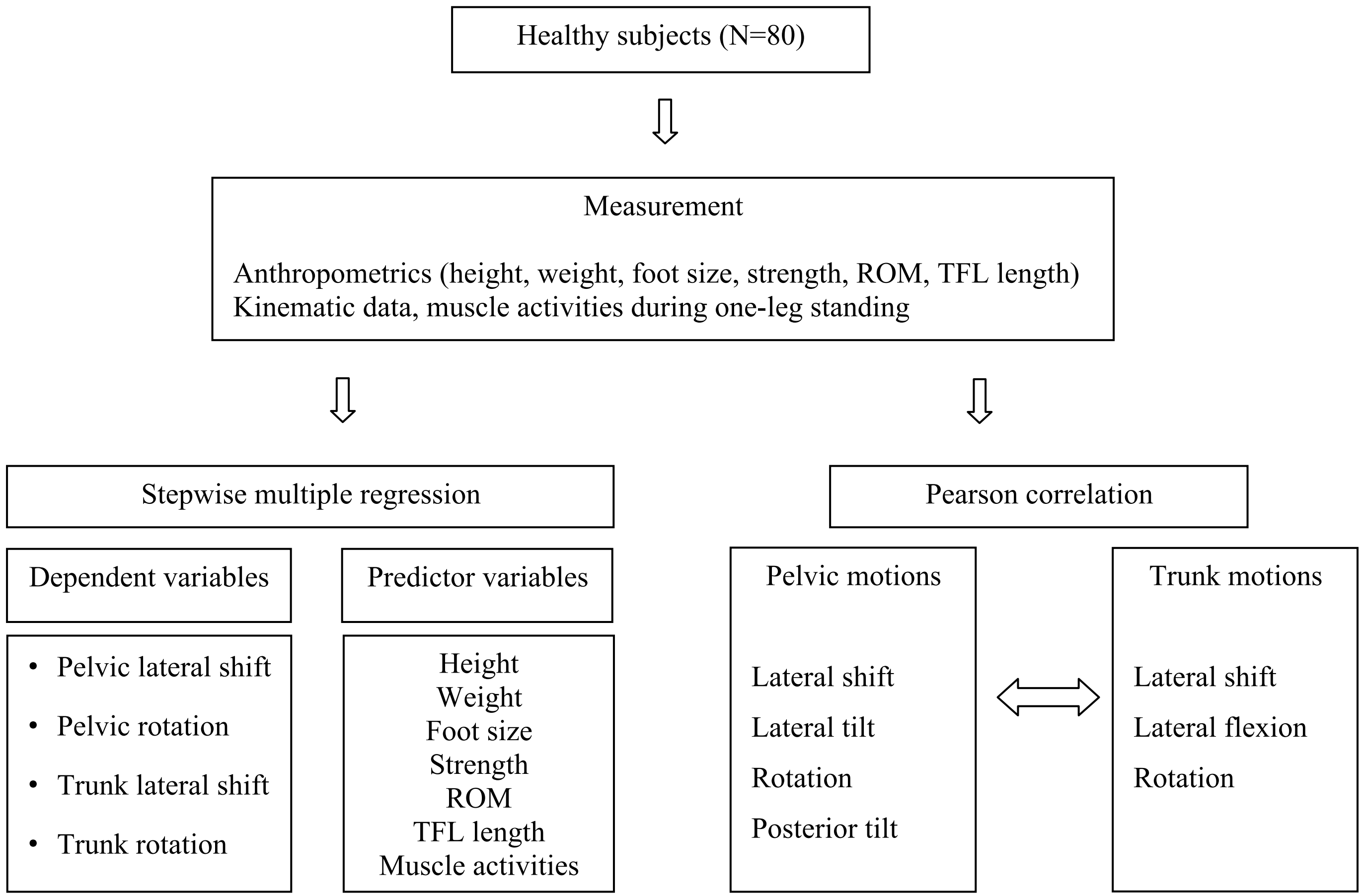


Figure 1. Flow chart for the experimental design.

2. Instruments

2.1 Isokinetic Dynamometer

The maximal isometric muscle strength of the trunk and hip joint were measured with an isokinetic device, consisting of a dynamometer, a positioning chair, a control panel, a system controller, a computer system, and various dynamometer attachments (Biodex System 3 Pro, Biodex medical, Shirley, NY, U.S.A.). In this study, two types of specialized back attachments were connected to the Biodex system for the measurement of lumbar flexor, extensor, and lumbar rotator.

2.2 Motion Analysis System

The pelvic and trunk motions were measured using a three-dimensional motion analysis system (CMS 70P, Zebris Medizintechnik, Gmbh, Isny, Germany); two sets of triple markers for the measurement of spine motions were applied with elastic Velcro strips (Figure 2). The system components were the CMS 70P basic unit with data transmission, the MA-XX measurement unit with three ultrasound transmitters, cable adapter, ultrasound body triple markers and computer system. The sampling rate for this study was 30 ㎐. The Windata 1.71 software was used for data analysis.

2.3 Surface Electromyography (EMG)

Muscle activity during the OLS test was collected via the wireless EMG system (TeleMyo DTS, Noraxon Inc., Scottsdale, AZ, U.S.A.) using silver-silver chloride dual surface electrodes (272, Noraxon Inc., Scottsdale, AZ, U.S.A.) (Figure 3). The TeleMyo DTS directly transmits myoelectric data from the electrodes to a belt-worn receiver.

2.4 Inclinometer

The inclinometer, a gravity goniometer (D-88316, Zebris Medizintechnik, Gmbh, Isny, Germany), was used for the analysis of the hip rotation range of motion (ROM) and the length of tensor fasciae latae (Figure 4).

2.5 Foot Measuring Device

The foot length and width of the subjects were measured with a foot-measuring device (Brannok Device Inc, NY, U.S.A.). The foot width was measured at its widest point (Figure 5).

Figure 2. Triple markers for the measurement of spine motions.

Figure 3. Wireless surface electromyography (TeleMyo DTS).

Figure 4. Inclinometer.

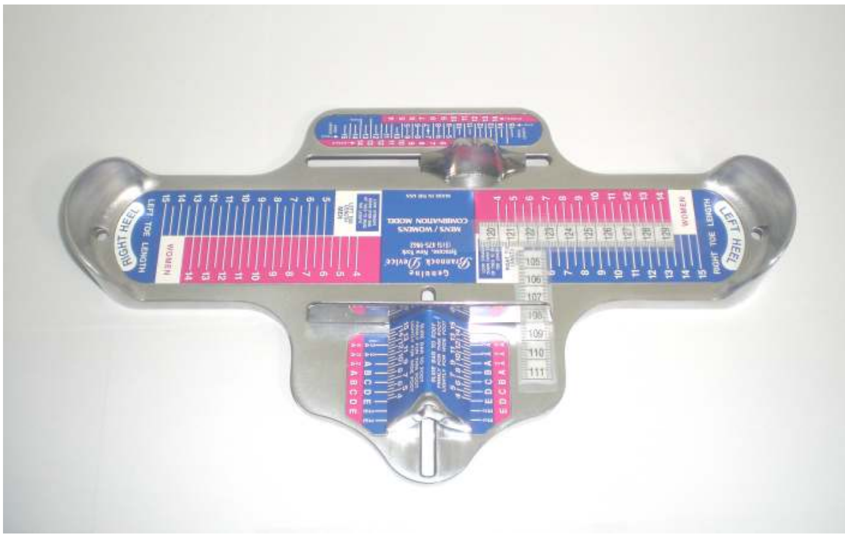


Figure 5. Foot measuring device.

3. Measurement

3.1 Pelvic and Trunk Motions

The three-dimensional motion analysis system was used to measure the motion of lateral shift, lateral tilt, posterior tilt, the rotation of the pelvis and lateral shift, lateral flexion, and the rotation of trunk during OLS. Operational definitions of pelvic and trunk motions are presented in Table 2.

A set of triple markers was applied to the subject, attached with Velcro strips. A further set of triple markers was placed at the midpoint, between the right and left anterior superior iliac spine (ASIS) using the elastic Velcro strip. Both sets of triple markers were aligned vertically to the midline of the trunk (Figure 6). The measuring sensor was located 1 meter away from the lateral side of the subject. To account for individual variability, the distance of the pelvic and trunk lateral shifts was normalized to the foot width (FW) of the dominant leg (%FW) (Suponitsky et al. 2008).

Table 2. Operational definitions of pelvic and trunk motions

Part	Motions	Operational definitions
Pelvis	Lateral shift	Horizontal displacement of the pelvis in frontal plane
	Lateral tilt	One ASIS[a] is higher than the other ASIS in frontal plane
	Posterior tilt	Both ASIS move posteriorly and superiorly in sagittal plane
	Rotation	One ASIS anterior to the other ASIS in horizontal plane
Trunk	Lateral shift	Horizontal displacement of the trunk in frontal plane
	Lateral flexion	Motions of the bending to one side in frontal plane
	Rotation	Motions of turning the spine to the side in horizontal plane

[a]ASIS: Anterior Superior Iliac Spine.

3.2 Muscle Activity

Surface electrodes were placed on both sides of the rectus abdominis and external oblique, dominant side of the TFL, and the gluteus medius muscles. The sampling rate was 1000 ㎐; the EMG signals were amplified and band pass-filtered at 20-450 ㎐ and the algorithm of electrocardiographic reduction was applied. The root-mean-square (RMS) values of the EMG data were calculated to quantify the amplitude of EMG signals, which was calculated from 300-㎳ windows of data points. The Myoresearch XP 1.07 software was used for data processing. The positions of the surface electrodes in each muscle were selected according to previous studies (Cram, Kasman, and Holtz 1998; Ng et al. 2002). The electrodes for the rectus abdominis were placed 1 ㎝ above the umbilicus and 2 ㎝ lateral to the midline. For the external oblique, electrodes were placed below the rib cage and along a line connecting the inferior point of the costal margin and the contralateral pubic tubercle. For the TFL, electrodes were placed parallel to the muscle fibers approximately 2 ㎝ below the ASIS. For the gluteus medius, electrodes were placed parallel to the muscle fibers over the proximal third of the distance between the iliac crest and the greater trochanter.

To normalize EMG activity, the maximal voluntary contraction (MVC) activity was measured for the tested muscles. The measurement positions for MVC were selected according to Kendall (Kendall et al. 2005). Each subject was asked to voluntarily and maximally contract each of the muscles for 5 s against the manual resistance of the examiner. The MVC value used the average RMS of three trials. The average EMG activity was expressed as a percentage of the MVC value (%MVC).

3.3 Muscle Strength

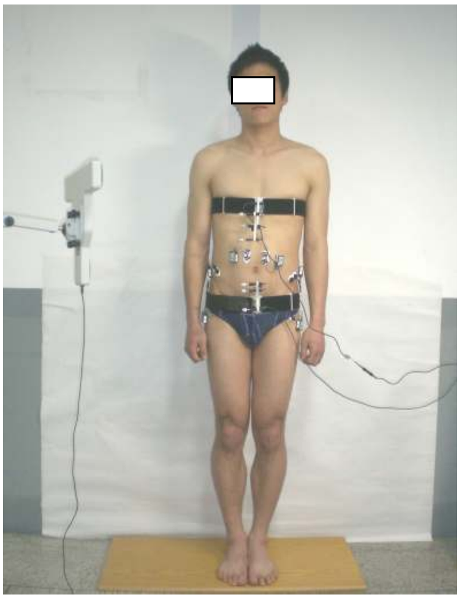
Maximal isometric muscle strength of the hip abductor and adductor, hip flexor and extensor, hip external rotator and internal rotator, lumbar flexor and extensor, and lumbar rotator were measured by the isokinetic device. The subject was asked to perform maximal isometric contraction for a period of 5 seconds. The mean peak torque in the three separate trials was used for data analysis. Trunk and pelvic straps were used to minimize compensatory motions during maximal isometric contraction. The value of the muscle strength was expressed as a percentage of each subject's body weight (%, [Nm/body weight] × 100). The ratio of hip abductor/adductor and hip external rotator/internal rotator strength was calculated in the statistical analysis.

3.4 Range of Motion (ROM) of Hip Rotation

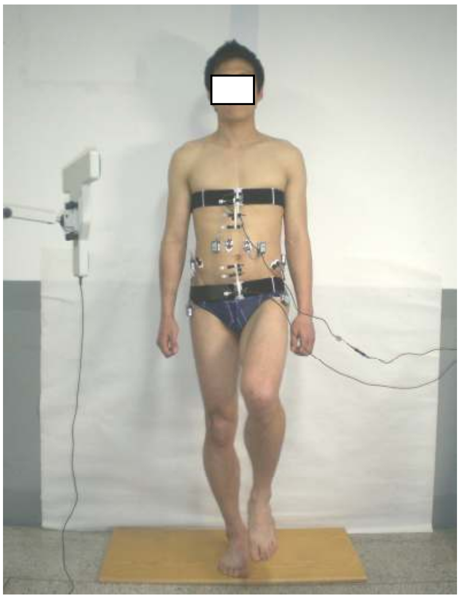
The ROM of hip internal and external rotation was measured using an inclinometer with the subject in the prone position, with the knee flexed to 90°. The gravity goniometer was placed on the medial surface of the lower leg, just proximal to the medial malleolus (Piva et al. 2006). The examiner fixed the pelvis of the subject using the examiner's forearm and the hip was passively rotated to the end of the range. The number of degrees on a scale of the inclinometer was recorded (Figure7).

3.5 Tensor Fasciae Latae Length (Ober test)

TFL length was measured using an inclinometer, as recommended by Hudson and Darthuy (2009). The subject was positioned on his/her side with the hip and knee of the lowermost side flexed to 45° and 90°, respectively. An elastic Velcro strip was wrapped around the pelvis at the level of the iliac crest to monitor the compensatory motion of the pelvis. Any inclination of vertical orientation of the elastic Velcro strip, elicited by a pelvic drop or hike during the Ober test was monitored visually by the examiner. The observed inclination was regarded as a compensatory motion of the pelvis, so that pelvic position was corrected by the examiner. The pelvis was stabilized by the examiner's hand and the uppermost knee was flexed to 90° and passively abducted and extended in line with the trunk by the other hand of the examiner. The subject was asked to relax all muscles of the lower extremities and the examiner lowered the uppermost leg towards the treatment table until slight resistance was felt at the end of the range. In this position, an assistant placed the inclinometer proximal to the lateral epicondyle of the femur (Figure 8). If the leg was horizontal, it was measured as 0°; if below horizontal (adducted), the angle was recorded as a positive number. If it was above horizontal (abducted), the angle was recorded as a negative number.



A. Double-leg standing.



B. One-leg standing.

Figure 6. One-leg standing.

Figure 7. Measurement of ROM of hip internal rotation.

Figure 8. Measurement of tensor fasciae latae length.

4. Procedure

For the starting position, the subject was asked to maintain the standing position comfortably, with both feet in close proximity on a hard wooden board for 5 seconds (Figure 6A). When signaled, the subjects lifted the non-dominant hip, which was flexed to 60° in the sagittal plane, while the lower leg was vertically hung with the ankle joint in a relaxed position for 5 seconds (Figure 6B). Kinematic data and EMG data were then recorded for 5 seconds. The maximal values of the pelvic and trunk motions during the OLS test were used for data analysis. Although previous literature reported no significant differences in the balance control between the non-dominant and dominant sides (Lin et al. 2009), this study selected the non-dominant leg to be lifted to maintain consistency throughout the OLS test. If the foot of the lifting leg touched the standing leg or the floor, or the subject balance was disturbed, the OLS test was repeated. A 1 minute rest period was provided between trials and the mean value of three trials was used for statistical analyses. Each subject was familiarized with the OLS test prior to data collection. Verbal instructions were offered to demonstrate the correct alignment and proper performance of the OLS test. All subjects reported confidence in sustaining 5 seconds in the OLS test.

5. Statistical Analysis

Statistical analyses were performed using the SPSS software (SPSS, Chicago, IL, U.S.A.). The one-sample Kolmogorov-Smirnov test was used to test for a normal distribution and the Pearson correlation was used to identify correlations between the pelvic and trunk motions during OLS. Stepwise multiple regression was used to determine factors that influenced pelvic and trunk motions during OLS. Intra-rater test-retest reliability of the measurements for TFL length, ROM of the hip joint, foot size, and pelvic width were assessed with intraclass correlation coefficients ($ICC_{3,1}$). A p-value < 0.05 was deemed to indicate statistical significance.

Results

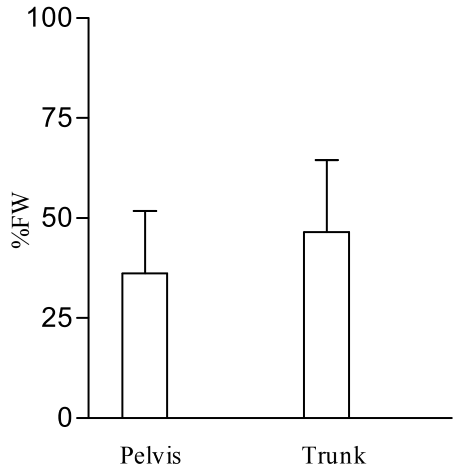
1. Motion Analysis During OLS

The mean values measured for the pelvic lateral shift were 3.4 ㎝ (36.19%FW) during the OLS test. The mean value for the trunk lateral shift in the OLS was 4.4 ㎝ (46.52%FW) (Table 3) (Figure 9).

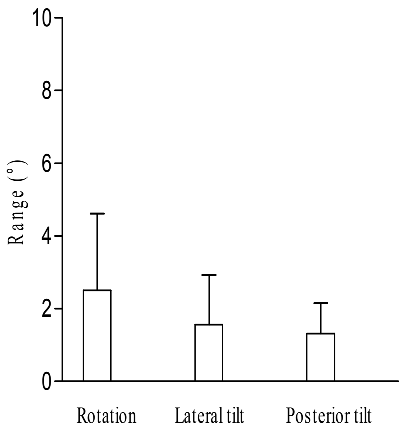
Table 3. Motion analysis of one-leg standing (N=80)

Part	Motion	Excursion
Pelvis	Lateral shift (%FW)	36.19 ± 15.61[a]
	Rotation (°)	2.50 ± 2.12
	Lateral tilt (°)	1.56 ± 1.37
	Posterior tilt (°)	1.32 ± 0.83
Trunk	Lateral shift (%FW)	46.52 ± 17.99
	Rotation (°)	2.62 ± 2.11
	Lateral flexion (°)	2.45 ± 1.75

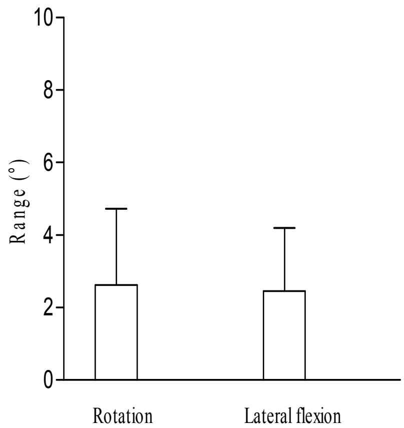
[a]Mean ± SD.



A. Lateral shift of pelvis and trunk.



B. Motions of the pelvis.



C. Motions of the trunk.

Figure 9. Motions of pelvis and trunk during one-leg standing.

2. Correlation Between Pelvis and Trunk Motions

Pelvic lateral shift showed a significant positive correlation with pelvic lateral tilt, trunk lateral shift, and trunk flexion, while a significant negative correlation was observed with the pelvis and trunk rotation (Table 4) (Figure 10). Pelvic rotation was negatively correlated with the pelvic lateral shift and the pelvic posterior tilt, while a positive correlation was observed with trunk rotation and trunk lateral flexion (Table 4) (Figure 10). A significant positive correlation was evident between trunk lateral shift and pelvic lateral tilt and between trunk lateral shift and trunk lateral flexion (Table 4) (Figure 10).

Table 4. Correlation between pelvic and trunk motions (N=80)

		Pelvis				Trunk		
		Lateral shift	Rotation	Lateral tilt	Posterior tilt	Lateral shift	Rotation	Lateral flexion
Pelvis	Lateral shift							
	Rotation	–0.26*						
	Lateral tilt	0.32*	–0.12					
	Posterior tilt	–0.04	–0.25*	–0.94				
Trunk	Lateral shift	0.67*	0.11	0.29*	–0.19			
	Rotation	–0.23*	0.87*	–0.01	–0.18	0.07		
	Lateral flexion	0.05	0.63*	0.08	–0.07	0.33*	0.43*	

* Pearson correlation coefficients ($p < 0.05$).

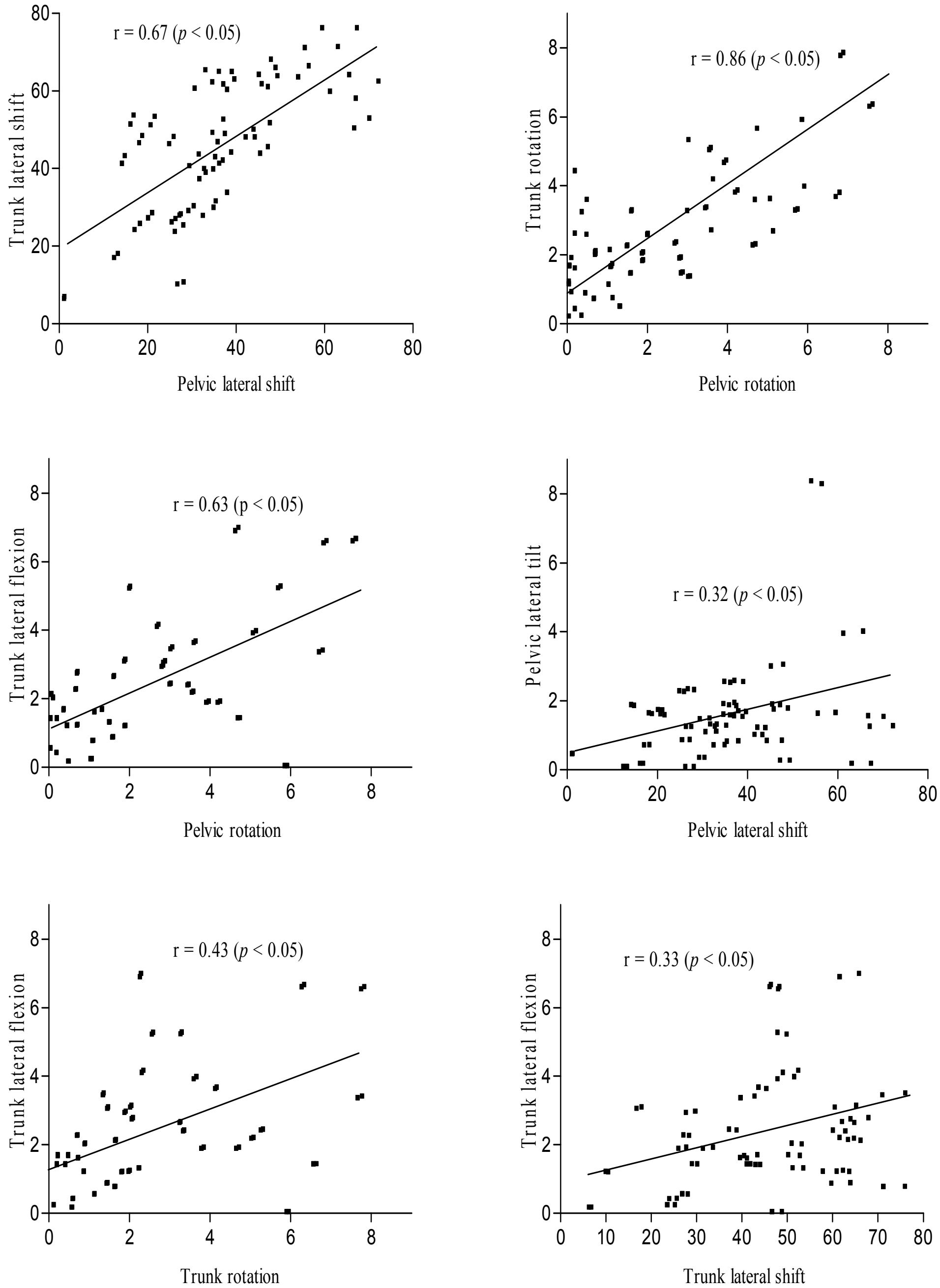


Figure 10. Correlation between pelvic and trunk motions (continued on next page).

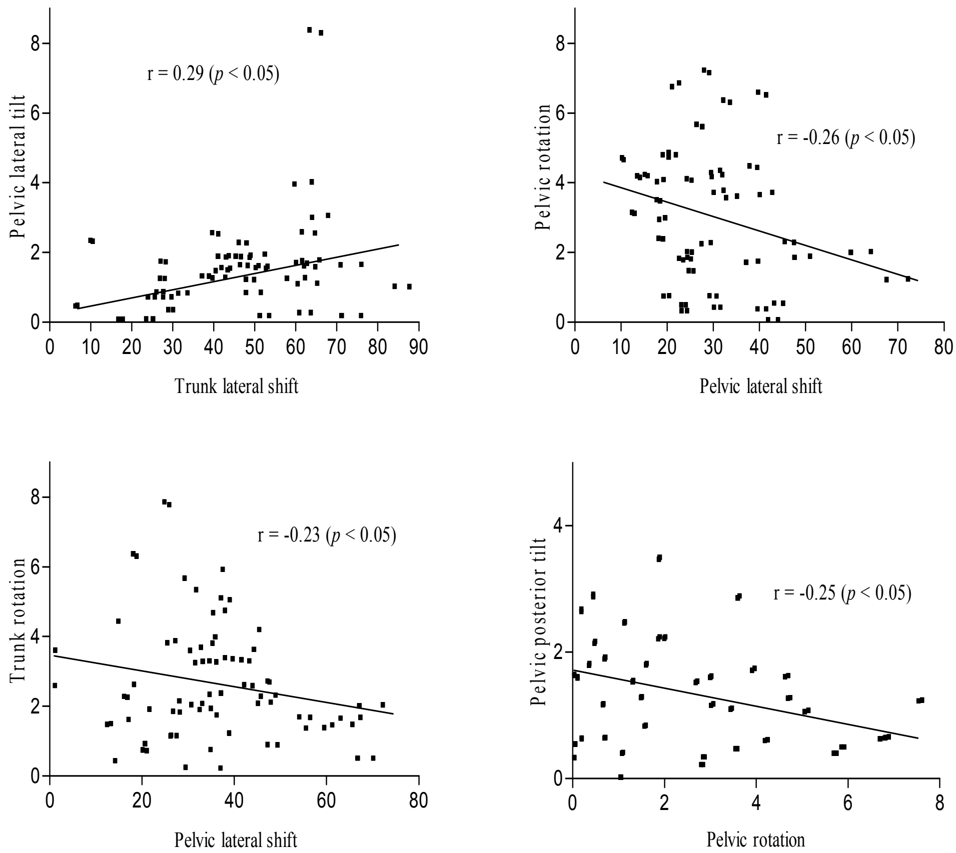


Figure 10. Correlation between pelvic and trunk motions.

3. Factors Influencing Pelvic and Trunk Motions

The results of the stepwise multiple regression analysis to determine factors that influenced the pelvic and trunk motions during OLS were shown in Table 4. Factors influencing the pelvic lateral shift were the foot length, the ratio of the hip abductor/adductor strength in the stance side, and the external oblique activity in the lift side. This regression equation accounted for 22% of the pelvic lateral shift (Table 5) (Table 6). The TFL length in the stance side and the ratio of the hip external/internal rotator strength of the stance side were factors found to have a significant influence on pelvic rotation. This regression equation accounted for 18% of the pelvis rotation (Table 5) (Table 6).

Factors influencing the trunk lateral shift were gluteus medius activity in the stance side, the external oblique activity in the lift side, the foot length, and the ratio of the hip abductor/adductor strength in the stance side. This regression equation accounted for 27% of the trunk lateral shift (Table 5) (Table 7). The TFL length in the stance side was the only factor found to have a significant direct influence on trunk rotation. This regression equation accounted for 14% of the trunk rotation (Table 5) (Table 7).

Table 5. Regression equations of pelvic and trunk motions (N=80)

Motions		Equation	R^{2a}
Pelvic lateral shift	=	183.82 – 4.95foot length – 0.23 ratio of abductor/adductor strength (stance side) – 0.77external oblique activity (lift side)	0.22
Pelvic rotation	=	4.37 – 0.16TFL length (stance side) – 0.02 ratio of external/internal rotator strength (stance side)	0.18
Trunk lateral shift	=	225.31 – 0.51gluteus medius activity (stance side) – 2.23external oblique activity (lift side) – 5.89foot length – 0.17 ratio of abductor/adductor strength (stance side)	0.27
Trunk rotation	=	4.26 – 0.17TFL length (stance side)	0.14

[a]R^2=Coefficient of determination.

Table 6. Multiple regression of factors influencing pelvic motions (N=80)

Pelvic motions	Factors	Unstandardized Coefficients		Standardized Coefficients	p
		β[d]	Standard error	β	
Lateral shift[a]	Constant	183.82	39.03		< 0.01
	Foot length	– 4.95	1.56	– 0.33	< 0.01
	Abductor/adductor strength (stance side)	– 0.23	0.08	– 0.29	< 0.01
	External oblique activity (lift side)	– 0.77	0.35	– 0.23	0.03
Rotation[b]	Constant	4.39	0.50		< 0.01
	TFL length (stance side)	–0.16	0.45	–0.43	0.01
	ER/IR[c] strength (stance side)	–0.02	0.00	–0.30	0.01

[a]R^2=0.22, SEE=14.13, F=6.789 ($p < 0.01$).
[b]R^2=0.18, SEE=1.93, F=17.146 ($p < 0.01$).
[c]ER/IR: External Rotator/Internal Rotator.
[d]β : Beta, regression coefficients.

Table 7. Multiple regression of factors influencing the trunk motions (N=80)

Trunk motions	Factors	Unstandardized Coefficients		Standardized Coefficients	*p*
		β [c]	Standard error	β	
Lateral shift[a]	Constant	225.31	49.73		< 0.01
	Gluteus medius activity (stance side)	–0.51	0.20	–0.27	0.01
	External oblique activity (lift side)	–2.23	0.65	–0.39	< 0.01
	Foot length	–5.90	1.93	–0.34	< 0.01
	Abductor/adductor strength (stance side)	–0.17	0.07	–0.26	0.01
Rotation[b]	Constant	4.26	0.51		< 0.01
	TFL length (stance side)	–0.17	0.46	–0.37	< 0.01

[a] R^2=0.27, SEE=15.76, F=6.960 ($p < 0.01$).
[b] R^2=0.14, SEE=1.97, F=12.71 ($p < 0.01$).
[c] β : Beta, regression coefficients.

4. Intrarater Reliability

The results of intrarater reliability of the measurements were showed in Table 8. The $ICC_{3,1}$ values ranged from 0.89 to 0.99 and showed excellent reliability.

Table 8. Intrarater reliability of measurement

Parameter	$ICC_{3,1}$	95%CI
TFL[a] length	0.89	0.80 - 0.94
Hip external rotation	0.97	0.95 - 0.98
Hip internal rotation	0.98	0.96 - 0.99
Foot length	0.99	0.99 - 0.99
Foot width	0.99	0.98 - 0.99
Pelvic width	0.94	0.90 - 0.97

[a]TFL: Tensor Faciae Latae.

Discussion

The OLS test is frequently used to assess lumbopelvic stability and movement quality clinically. The purpose of this study was to determine factors that influenced pelvic and trunk motion during OLS.

In the kinematic results, the mean value for the pelvic lateral shift in the OLS was 3.4 ㎝. It has been previously reported that the normal displacement to the stance leg should not be more than 1 inch without any compensatory movement (Janda, and Va'vrova 1996; Liebenson 2005; 2007). Other studies have indicated that the correct movement is not greater than a 10 ㎝ lateral shift in motion during OLS. These studies did not provide data to support their criteria concerning the degree of pelvic displacement during OLS (Luomajoki et al. 2007; 2008). Suponitsky and colleagues (2008) studied fatigue of the shank muscles in OLS sway and observed a center of pressure that moved from 41.5% FW to 48.6% FW in the medio-lateral direction.

With a lack of qualitative research data, previous studies have suggested that if trunk shift or trunk lateral flexion occurs from the initial vertical position during the OLS test, it can be regarded as an incorrect movement pattern (Fritz, and George 2000; O'Sullivan 2000; Sahrmann 2002). In this study, the average peak value of the trunk lateral shift, trunk rotation, and trunk lateral flexion were 4.4 ㎝, 2.6°, and 2.5°, respectively. Further studies are required to define the criteria of the trunk motion occurring during the OLS test.

Previous reports have described criteria for pelvis displacement in the frontal plane during OLS. Furthermore, Sharman (2002) proposed that the pelvic rotation in the transverse plane and lateral tilting in frontal plane should not occur whilst maintaining OLS. However, they evaluated pelvic rotation and pelvic tilt using only visual judgment. This study is provided here the first measurements of pelvic rotation and pelvic tilt during the OLS test. The current study demonstrated that a 2.5° pelvic rotation and 2.6° trunk rotation occur in healthy subjects with no lower back pain. Further studies are required to compare pelvic and trunk rotation in both symptomatic and asymptomatic subjects during the OLS test.

A step-wise multiple regression analysis indicated that foot length, the ratio of the hip abductor/adductor strength in the stance side, and external oblique activity in the lift side were significant negative factors that influenced pelvic lateral shift. When an individual with a large foot length performed the OLS test, the degree of pelvic lateral shift decreased. The area of the base of support affects the stability of body. A longer foot provides an increased area of support, which may be why foot length was determined to be a major influencing factor for the pelvic lateral shift.

The OLS test has previously been used to assess gluteus medius strength and pelvic drop was observed as a result of a weakened strength of hip abductors (Millisdotter, Stromqvist, and Jonsson 2003). In this study, the ratio of hip abductor/adductor strength in the stance side was also a negative factor for pelvic lateral shifts.

Previous studies have reported that the abdominal muscle activity affects both trunk and lumbopelvic stability during load transfer (Richardson et al. 2002). The global muscles of the trunk (such as the external oblique) are concerned with producing and controlling both the trunk and pelvis movements (Richardson et al. 2002). Sahrmann (2002) suggested that control of the external oblique muscle is necessary to properly stabilize the spine, maintain the optimal alignment and movement, and prevent excessive stress and compensatory motions of the pelvis during movements of the extremities. The current study demonstrated that the muscle activity of the external oblique contributed to the decreased pelvic lateral shift observed. The increased muscle activity of the external oblique may, thus, contribute to stabilization of the pelvic and trunk segments during the OLS test.

The influencing factors with regard to pelvic rotation were the TFL length in the stance side and the ratio of the hip external/internal rotator strength in the stance. The function of TFL is the flexion, internal rotation, and abduction of the hip joint (Kendall et al. 2005; Sahrmann 2002). Previous studies suggested that TFL shortness contributed to pelvic rotation while the foot was fixed on the ground during OLS or walking (Hudson and Darthuy 2009; Sahrmann 2002). The findings of this study indicate that the length of TFL negatively contributes to pelvic rotation.

The muscle balance of the hip internal and external rotators is required to stabilize the hip joint while the OLS or stance phase of walking occurs. An insufficiency of hip external rotator muscle strength may induce a hip internal rotation when weight is focused onto one leg. If the hip internal rotation occurs during OLS, this may cause pelvic rotation. Thus, a decreased ratio of hip external/internal rotator strength caused an increase in the pelvic rotation.

Factors that influenced trunk lateral shift were the external oblique muscle activity in the lift side, the foot length, gluteus medius activity in the stance side, and the ratio of the hip abductor/adductor strength in the stance side. Regarding the pelvic lateral shift, the external oblique activity was a significant factor that affected the trunk lateral shift. This muscle originates from the ribs and inserts to the pubic symphysis and linea alba. By attaching to the rib cage, the external oblique muscle contributes to the observed trunk stability. Thus, the increase in the external oblique muscle activity decreased the pelvic lateral shift. Regarding pelvic lateral shift, foot length was a significant factor that affected the trunk lateral shift. A decreased trunk lateral shift was considered to be the result of an increased base of support. Winter and colleagues (1996; 1998) stated that stiffness control was modulated at the hip abductor/adductor muscles for frontal plane motion. In this study, an increase in the ratio of hip abductor/adductor strength and gluteus medius muscle activity contributed to the improvement of lumbopelvic and trunk stability.

The single factor affecting trunk rotation was observed to be the length of TFL. As described in the pelvic rotation, TFL shortness led to the rotation of the upper segment (pelvis and trunk) during OLS.

Both the pelvis and lumbar vertebrae are linked with multiple segments and as such, many degrees of freedom exist. Both the pelvic and trunk motions interact during movement; however, previous studies described only a single region (pelvis or trunk) and a one-dimensional motion (lateral shift or rotation) during the OLS test (Fritz, and George 2000; Janda, and Va'vrova 1996; Liebenson 2005; Luomajoki et al. 2007; 2008; Millisdotter, Stromqvist, and Jonsson 2003; O'Sullivan 2000; Roussel et al. 2007; Sahrmann 2002; Tidstrand, and Horneij 2009). Here, this study show that pelvic motion correlated with trunk motion. The current study observed a moderate-to-positive correlation between the pelvic lateral shift and the trunk lateral shift (r=0.67), between the pelvic and trunk rotation (r=0.86), and between pelvic rotation and trunk lateral flexion (r=0.63), while a negative correlation was observed between pelvic lateral shift and pelvic rotation (r=-0.26), and pelvic lateral shift and trunk rotation (r=-0.23). Thus, both pelvic and trunk motions should be considered during the OLS test as a determinant of the movement dysfunction of lumbopelvic stability.

The current study has some limitations. This study did not confirm the motion of the lower extremities: particularly, the hip, knee, or ankle joint. The stability of pelvic motion may be controlled by co-contraction of the transverses abdominis, internal oblique, and multifidus (Hungerford, Gilleard, and Hodges 2003; Snijders et al. 1998; Vleeming et al. 1995); however, EMG muscle activity in the lower extremities and the deep muscle of the trunk were not measured in this study. Additionally, these results may not be generalized to other populations, because the subjects in this study were healthy and young. Further studies are required to determine the effects of strength and kinematics of the knee and ankle joints and the muscle activity of the lower extremities and deep trunk muscles on the pelvic and trunk motions. Additionally, a cutoff value for the pelvic and trunk motions between normal and abnormal is required for improving validity and reliability of the OLS test.

Conclusion

Factors influencing the pelvic lateral shift were the foot length, the ratio of the hip abductor/adductor strength in the stance side, and the external oblique activity in the lift side. The TFL length in the stance side and the ratio of the hip external/internal rotator strength of the stance side were factors found to have a significant influence on pelvic rotation. Factors influencing the trunk lateral shift were gluteus medius activity in the stance side, the external oblique activity in the lift side, the foot length, and the ratio of the hip abductor/adductor strength in the stance side. The TFL length in the stance side was the only factor found to have a significant direct influence on trunk rotation.

This study indicates that both pelvic and trunk motions should be considered during the OLS test as a determinant of movement dysfunction in lumbopelvic stability. Additionally, this study suggests that the muscle activity of the external oblique and gluteus medius, the ratio of hip abductors/adductors strength, and the ratio of hip external/internal strength, and the length of TFL should all be included in both the evaluation and treatment of lumbopelvic stability.

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국문 요약

한발서기 시 골반과 체간 동작에 영향을 주는 요인

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한발서기 검사는 임상에서 균형 능력뿐만 아니라 요추-골반의 안정성을 평가하기 위해서 사용되고 있다. 본 연구의 목적은 젊고 건강한 대상자에서 한발서기 시 골반과 체간의 정상적인 동작을 알아보고, 골반의 동작과 체간의 동작 사이의 상관관계를 확인하며, 골반과 체간 동작에 영향을 주는 요인들을 결정하는 것이었다. 본 연구에 80명의 건강한 대상자가 지원하였다. 대상자들의 인체계측 특징을 측정하였고, 등속성

장비를 이용하여 대상자들의 고관절과 체간 근육의 최대 등척성 근력을 측정하였다. 한발서기 시 골반과 체간의 동작을 삼차원 동작분석기를 이용하여 측정하였고, 표면 근전도기기를 이용하여 고관절과 복부 근육의 근활성도를 측정하였다. 골반과 체간 동작들 사이의 관계를 확인하기 위하여 피어슨 상관분석을 사용하였다. 단계별 다중회귀분석을 통하여 한발서기 시 골반과 체간의 동작에 영향을 주는 예측 변수를 확인하였다.

한발서기 시 골반의 동작과 체간의 동작은 유의한 상관관계를 보였다. 골반의 외측 변위에 영향을 주는 요인들은 발 길이, 지지하는 측의 고관절 외전근과 내전근의 근력 비, 들고 있는 측의 외복사근의 근활성도였다 (R^2=0.22). 지지하는 측의 대퇴근막장근의 길이와 고관절 외회전근과 내회전근의 근력 비가 골반의 회전에 유의한 영향을 주는 요인들이었다 (R^2=0.18). 체간의 외측 변위에 영향을 주는 요인들은 지지하는 측의 중둔근 근활성도, 고관절 외전근와 내전근의 근력 비, 발 크기, 들고 있는 측의 외복사근의 근활성도였다 (R^2=0.27). 지지측의 대퇴근막장근의 길이가 체간의 회전에 영향을 주는 유일한 요인이었다 (R^2=0.14).

본 연구에서는 요추–골반 안정성의 운동 장애를 평가하기 위해서 한발서기 검사 시 골반과 체간 동작이 함께 고려되어야 할 것으로 사료된다. 또한, 본 연구에서는 요추–골반 안정성을 위해서 외복사근과 중둔근의 근활성도, 고관절 외전근과 내전근의 근력비, 고관절 외회전과

내회전의 비, 그리고 대퇴근막장근의 길이가 평가와 치료를 위해 포함되어야 할 것으로 사료된다.

핵심되는 말: 요추–골반 안정성, 자세조절, 한발서기.