

The influences of restricted compensatory movement on activation pattern of gluteal muscles during unilateral weight-bearing exercise

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ABSTRACT

We investigated changes in lateral pelvic tilt and activity of the gluteal muscles during one-leg standing with and without pressure biofeedback. Seventeen participants performed one-leg standing tests with pressure biofeedback (the threshold was set to the minimum change in pressure) and without biofeedback (standard one-leg standing). The lateral pelvic tilt was significantly lower in one-leg standing with pressure biofeedback than in standard one-leg standing ($p < .05$). In addition, gluteus medius and gluteus maximus activity was significantly greater during one-leg standing with pressure biofeedback than during standard one-leg standing ($p < .05$). Based on our results, restriction of compensatory movement can be used to increase activity of gluteal muscles when performing unilateral weight-bearing exercise such as one-leg standing.

Keywords: Biofeedback; Buttocks; Exercise; Posture.

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INTRODUCTION

The gluteus medius (Gmed) is wide and fan shaped (Pfirrmann et al., 2001), and its primary role is as a hip abductor. It accounts for 60% of the total cross-sectional area of the hip abductor muscles (Clark and Haynor, 1987). The gluteus maximus (Gmax) has the largest cross-sectional area of the hip muscles (Reiman et al., 2012) and acts as a hip abductor as well as a powerful hip extensor and external rotator (Nakagawa et al., 2008; Reiman et al., 2012; Wilson et al., 2006). These two muscles support weight-bearing activities by assisting in load transfer and maintaining the alignment of the lower extremities (Lee, 1996). Weakness of the Gmed and Gmax is linked to lower extremity injuries and lower back pain (LBP) (Akuthota and Nadler, 2004; Brindle et al., 2003). Gmed and Gmax strengthening exercises are used to treat and prevent lower extremity injuries and back pain, and weight-bearing exercise is recommended because it requires greater muscle activity than non-weight-bearing exercise (Macadam et al., 2015).

One-leg standing (OLS) is a weight-bearing exercise that is used to strengthen hip abductor muscles (Krause et al., 2009). The hip abductors generate a force equal to twice the body's weight to maintain the correct pelvic and torso posture during OLS (Neumann, 1989), and they have the muscle length to produce the greatest torque in the OLS condition (Neumann et al., 1988). However, pelvic deviation may occur to the support side due to the shift of the body's centre of gravity during OLS, and this leads to a contralateral pelvic depression, which may cause weakening of the hip abductors (Fujita et al., 2017; Grimaldi, 2011). Previous studies have shown that ipsilateral deviation of the pelvis during OLS decreases Gmed muscle activity (Fujita et al., 2017; Prior et al., 2014). Therefore, to increase activity of the hip abductor muscles during OLS, there is a need to minimize pelvic deviation.

Pressure biofeedback is a way to check the change in pressure at the contact area in real time, which is useful for identifying deviations in body alignment during exercise. Thus, since the deviation of the trunk or pelvis can be checked in real time during OLS, pressure biofeedback can be used to improve lumbopelvic alignment and correct muscle activity (Cynn et al., 2006; Noh et al., 2014; Oh et al., 2007; Yu et al., 2018). Cynn et al. (2006) reported a decreased pelvic lateral tilt angle and increased Gmed activity during side-lying hip abduction with pressure biofeedback compared to without. A similar study demonstrated that the pelvic anterior tilt angle decreased and hip extensor muscle activity increased during prone hip extension with the addition of pressure biofeedback (Oh et al., 2007). It has also been demonstrated that the application of pressure biofeedback during active straight leg raise (ASLR) tests increased abdominal activity while decreasing pelvic rotation (Noh et al., 2014), and Yu et al. (2018) observed that infraspinatus activity increased and posterior deltoid activity decreased when the pressure was maintained at 2 mmHg using pressure biofeedback during prone shoulder external rotation.

Previous studies have shown that the pressure biofeedback method is useful to correct movement patterns and increase muscle activity during therapeutic exercise (Cynn et al., 2006; Noh et al., 2014; Oh et al., 2007; Yu et al., 2018). However, no studies have investigated the effects of pressure biofeedback on gluteal muscle activity and pelvic lateral tilt during OLS. In addition, the pressure biofeedback unit used in previous studies has a scale with a narrow range, which makes it difficult to identify accurately during exercise.

The purpose of this study was to investigate differences in the activities of the Gmed and Gmax during the OLS test with and without pressure biofeedback. As a secondary measure, we recorded the difference in lateral pelvic tilt during OLS with and without pressure biofeedback.

MATERIALS AND METHODS

Participants

Seventeen healthy male subjects (age 31.26 ± 2.53 years, height 176 ± 2.66 cm, weight 73.89 ± 3.85 kg) participated in this study. The inclusion criteria included no history of low back pain or lower extremity pain and the ability to maintain OLS for more than 5 s. Subjects were excluded if they could not maintain the correct posture during OLS or if the exercise generated pain in the lower back or lower extremity. Prior to the study, all participants read and signed an informed consent form approved by the Pukyong National University Institutional Review Board.

G*power software was used to determine the necessary sample size (ver. 3.1.2; Franz Faul, University of Kiel, Kiel, Germany). The power analysis was conducted based on a previous study (Fujita et al., 2017) and indicated that at least 14 participants would be required to achieve a power of 0.80 with a large effect size of 0.8 at an α level of 0.05. Owing to the possibility of withdrawals and data loss, we recruited 17 subjects.

Procedure

Before starting the experiment, all participants completed a questionnaire related to demographic parameters. The examiners then measured lateral pelvic tilt and activity of the Gmed and Gmax during two types of OLS. Two examiners were involved in this study. While performing the OLS test, examiner 1 measured lateral pelvic tilt and examiner 2 measured muscle activity.

A wireless TeleMyo Direct Transmission System (Noraxon Inc., Scottsdale, AZ, USA) and Myo-Research Master Edition 1.06 XP software were used to measure electromyographic (EMG) activity of the Gmed and Gmax in the dominant leg. The dominant leg was defined as the kicking leg (Krause et al., 2009). Before placing the two bipolar electrodes, the skin was shaved and cleaned using a disposable alcohol swab to reduce skin impedance. The surface electrode pairs (AG/AGCl) had a pre-gelled diameter of 15 mm and were attached 2 cm apart. The EMG electrode for the Gmed was placed on the proximal side, one-third of the distance between the iliac crest and greater trochanter; the EMG electrode for the Gmax was positioned halfway between the trochanter and sacral vertebrae in the middle of the muscle at an oblique angle at the level of the trochanter. The EMG electrodes were placed parallel to the direction of the muscle fibres in the middle of the muscle belly. The raw EMG signals were sampled at 1,000 Hz with a band pass filter at 20–450 Hz and notch filter at 60 Hz. All EMG data were processed to root mean square values with a 50 ms window.

Normalization of the EMG data was performed using a maximal voluntary isometric contraction (MVIC). The MVIC of the Gmed muscle was measured in the side-lying position. When the subjects performed hip abduction with maximal effort, the examiner applied manual resistance to the ankle (Kang et al., 2019). The MVIC of the Gmax muscle was measured in the prone position with 90° of knee flexion (Willcox and Burden, 2013). The subjects were asked to extend the hip with maximal effort while the examiner provided manual resistance to the lower part of the posterior thigh. The MVIC of each muscle was performed for 5 s and 10 min of rest time was provided between each trial. The middle 3 s of EMG data from three trials were used to calculate a mean value, which was used as the MVIC. The mean percentage MVIC (% MVIC) of three OLS trials was used for data analysis.

Lateral pelvic tilt was measured to analyse pelvic alignment during OLS. A marker was attached to each anterior superior iliac spine (ASIS) and a digital camera was placed 2.5 m from the subject according to the subject's ASIS height. A photographic image was taken during OLS, and the lateral pelvic tilt was measured

as the angle between a horizontal line and a line connecting the ASISs (Prior et al., 2014; Figure 1). All photographic images were analysed using ImageJ (ver. 1.44) (Edmondston et al., 2013). The average of three measurements was used for data analysis.



Figure 1. Measurement of lateral pelvic fit.

All OLS tests were performed on the dominant side. Prior to the experiment, all subjects practiced OLS for 10 min under the supervision of an examiner. Subjects randomly performed standard OLS and OLS with pressure biofeedback (OLSPB).

OLS was performed with reference to the study of Edmondston et al. (2013). The subjects were asked to stand barefoot with their feet together and their arms across their chest. The subjects were instructed to flex the hip 30° on the non-support side. A target bar was used to confirm that the participants performed 30° of hip flexion during the trials (Figure 2A).

OLSPB was performed in the same way as standard OLS except for the addition of pressure biofeedback (Figure 2B). The 4D-MT pressure sensor (ReLive, Seoul, Korea) was used to check the pressure changes in real time during OLS. This equipment consists of a cuff device that senses pressure. The pressure data were sent to an Android tablet PC, and the pressure changes were displayed on the screen in real time. Prior to performing OLSPB, a pressure sensor was placed between the lateral shoulder on the non-support side and the wall and calibration was performed. The threshold was set to the minimum change in pressure during OLSPB. The change in pressure on the tablet screen was expressed as a bar; subjects were asked to avoid

raising the bar, if possible, during the OLSPB. If an abnormal posture such as increased thoracic kyphosis, lumbar lordosis or kyphosis, trunk rotation, or knee flexion of the support leg appeared, data collection was discontinued. OLS was maintained for 5 s and rest time was provided between trials, along with a 20 min rest between OLS conditions to reduce fatigue and learning effects.

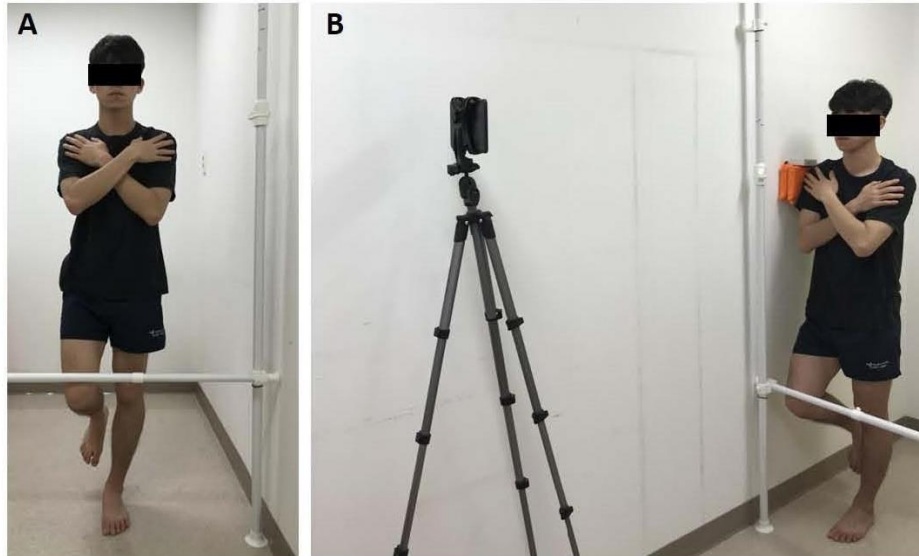


Figure 2. Standard one-leg standing (A) and one-leg standing with pressure biofeedback (B).

Statistical analysis

The Kolmogorov-Smirnov test was used to verify the normality of the outcome measures. All variable data are expressed as the mean ± standard deviation. The paired *t*-test was used to compare EMG data of the Gmed and Gmax and lateral pelvic tilt. The level of statistical significance was set at *p* < .05. All variable data were analysed using SPSS ver. 20.0 (IBM Corp., Armonk, NY, USA).

RESULTS

Table 1. Changes in activity of the gluteal muscles and lateral pelvic tilt during one-leg standing with and without pressure biofeedback.

	Standard OLS	OLSPB	P	95% CI
Gluteus medius (%MVIC)	19.96 ± 9.20	23.69 ± 10.19	.015*	-6.65 – -0.81
Gluteus maximus (%MVIC)	4.55 ± 2.16	6.81 ± 4.72	.034*	-4.33 – 0.19
Lateral pelvic tilt (°)	3.63 ± 1.59	1.04 ± 0.54	< .001*	1.88 – 3.30

CI, confidence interval; *MVIC*, maximal voluntary isometric contraction; *OLS*, one leg standing; *OLSPB*, one leg standing with pressure biofeedback. **p* < .05.

The Kolmogorov-Smirnov test showed normality in all outcome variables (*p* > .05). The muscle activity and lateral pelvic tilt data from during OLS are shown in Table 1. The activity of the Gmed and Gmax was

significantly greater during OLSPB compared with standard OLS ($p < .05$). A significant reduction in lateral pelvic tilt was observed during OLSPB compared to standard OLS ($p < .05$).

DISCUSSION

The purpose of our study was to examine the effect of pressure biofeedback on pelvic alignment and gluteal muscle activity during OLS in healthy men. Our findings show that the lateral pelvic tilt was decreased and activity of the Gmed and Gmax was increased during OLSPB compared to OLS.

Compared to standard OLS, the lateral pelvic tilt angle was 71% during OLSPB. This may be explained by the subjects controlling their trunk deviation by checking the pressure changes in real time. If trunk deviation on the non-supported side occurs, a pelvic deviation occurs on the supported side, which is related to lateral pelvic tilt (Fujita et al., 2017; Grimaldi, 2011). An increase in pressure during OLS means that the deviation of the trunk increased on the unsupported side. These results are consistent with previous findings (Cynn et al., 2006; Noh et al., 2014; Oh et al., 2007; Yu et al., 2018). Noh et al. (2014) reported that the pelvic rotation angle was decreased during ASLR tests with pressure biofeedback compared to without biofeedback in patients with LBP. Cynn et al. (2006) demonstrated that side-lying hip abduction with pressure biofeedback resulted in significantly lower lateral pelvic tilt than without pressure biofeedback, while Oh et al. (2007) showed that the pelvic anterior tilt was significantly reduced during prone hip extension with pressure biofeedback. Based on our results and those of previous studies, we conclude that pressure biofeedback is a useful method to correct pelvic alignment during OLS.

The activity of the Gmed and Gmax was 18% and 50% greater during OLSPB than during standard OLS, respectively. The Gmax and Gmed act as hip abductors (Clark and Haynor, 1987; Wilson et al., 2006), which provide pelvic stability on the frontal plane during OLS (Hurwitz et al., 2003). If lateral pelvic tilt increases during OLS, this indicates a weakening of the hip abductors (Fujita et al., 2017). In contrast, when lateral pelvic tilt decreases, the internal moment arm decreases (Henderson et al., 2011), and the hip abductor requires greater activation to maintain this position (Kang et al., 2019). Our findings confirm that the lateral pelvic tilt was decreased during OLSPB. For this reason, the activity of the Gmed and Gmax seems to increase during OLSPB. In addition, both muscles contribute to weight bearing by controlling load transfer through the hip joint (Lee, 1996). Because pelvic alignment was better maintained under the OLSPB condition than standard OLS, the activity of both muscles seems to be greater. Previous studies have reported significant increases in the activity of the Gmed and Gmax during weight-bearing exercises, which supports our findings (Macadam et al., 2015; Reiman et al., 2012). Some previous research is consistent with our results (Cynn et al., 2006; Noh et al., 2014; Oh et al., 2007; Yu et al., 2018). Yu et al. (2018) found that infraspinatus activity increased and posterior deltoid activity decreased when the pressure was maintained at 2 mmHg during prone shoulder external rotation with pressure biofeedback in healthy men, and other researchers showed that dual pressure biofeedback during ASLR significantly increased abdominal muscle activity in patients with LBP (Noh et al., 2014). In other studies, the activities of the Gmed and hip extensor muscles were greater during hip abduction and hip extension using pressure biofeedback, respectively (Cynn et al., 2006; Oh et al., 2007). Therefore, OLSPB can be suggested as a useful exercise to increase the activity of the Gmed and Gmax.

In clinical or sports settings, strengthening exercises for the Gmed and Gmax are commonly used for LBP and to prevent lower limb injury. While OLS is used during various movements, compensatory movements such as pelvic lateral tilt can occur. Thus, in this study, the control of trunk deviation using pressure biofeedback during OLS resulted in increased activity of the gluteal muscles and decreased lateral pelvic tilt.

The implication of these results is that pressure biofeedback during OLS is effective for increasing the activity of the gluteal muscles and for correcting pelvic alignment.

Our study has some limitations. First, we only investigated healthy men. Future studies should determine the effect of pressure biofeedback during OLS in patients with LBP or lower extremity injury. Second, we only evaluated pelvic movements in the frontal plane. Additional studies should include measurements of pelvic movement in the sagittal and horizontal planes as well as in the frontal plane. Third, since our study only examined the short-term effects of pressure biofeedback, no long-term effects are known.

CONCLUSION

We investigated muscle activity in gluteal muscles and lateral pelvic tilt during OLS with and without pressure biofeedback. Our findings demonstrated that OLSPB significantly increased Gmed and Gmax, together with decreasing lateral pelvic tilt than standard OLS. These results may help clinicians to design effective exercise programs to increase gluteal muscles and correct pelvic alignment.

AUTHOR CONTRIBUTIONS

- 1) Conception and design, or acquisition, or analysis and interpretation of data: Kim SY, Kang MH.
- 2) Drafting the article or revising it critically for important intellectual content: Kim SY, Kang MH.
- 3) Final approval of the version to be published: Kim SY, Kang MH.

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DISCLOSURE STATEMENT

No potential conflict of interest relevant to this article was reported.

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