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Effects of real-time visual biofeedback of pelvic movement on electromyographic activity of hip muscles and lateral pelvic tilt during unilateral weight-bearing and side-lying hip abduction exercises

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ABSTRACT

Although neutral pelvic alignment is important for hip abduction exercises, studies exploring objectively monitored pelvic alignment on the gluteus medius (Gmed) muscle activity during hip abduction exercises, especially under weight-bearing (WB) conditions, are limited. Therefore, we examined the effects of real-time visual biofeedback (RVBF) of pelvic movement on electromyographic (EMG) activity of hip muscles and lateral pelvic tilt during unilateral WB and side-lying hip abductions. Fifteen male participants performed unilateral WB and side-lying hip abduction exercises with and without RVBF. Under the RVBF condition, participants monitored pelvic movements in real time during hip abduction exercises. EMG activity of Gmed and quadratus lumborum (QL) as well as lateral pelvic tilt angle were recorded during each hip abduction exercise. Gmed EMG activity increased, while lateral pelvic tilt decreased during both hip abduction exercises with RVBF ($p < 0.05$). Additionally, the changes in Gmed activity, the Gmed/QL activity ratio, and the lateral pelvic tilt angle under RVBF were greater during unilateral WB hip abduction than during side-lying hip abduction ($p < 0.05$). These results suggest that RVBF of pelvic movement could be useful to strengthen Gmed and prevent compensatory lateral pelvic movement during hip abduction exercises, especially in the unilateral WB position.

1. Introduction

Weakness of the hip abductor muscles is associated with lower extremity injuries including patellofemoral pain syndrome (Van Cant et al., 2017), ankle sprain (Powers et al., 2017), and iliotibial band syndrome (Mucha et al., 2017). Among the hip abductor muscles, the gluteus medius (Gmed) is a primary mover and has the largest muscle volume (Flack et al., 2014). In addition, Gmed plays an important role in ensuring correct pelvic alignment in the frontal plane (Neumann, 2017). To prevent and treat lower extremity injuries, Gmed strengthening exercises are performed in clinics.

Non-weight-bearing hip abduction with the knee extended and no hip flexion/extension, such as side-lying hip abduction, is the most commonly performed Gmed strengthening exercise in the clinical setting (McBeth et al., 2012). Side-lying hip abduction leads to increased Gmed muscle activation (Distefano et al., 2009; McBeth et al., 2012). However, side-lying hip abduction also increases activation of the quadratus lumborum (QL), which is the agonist of lateral pelvic tilt (Cynn et al., 2006; Park et al., 2010). Thus, for effective hip abduction exercises, selective Gmed activation is required to prevent excessive QL activation and compensatory lateral pelvic tilt.

In addition to side-lying hip abduction, unilateral weight-bearing (WB) exercises including one-leg squat, side stepping, and unilateral WB hip abduction can strengthen Gmed (Bolgla and Uhl, 2005; Barton et al., 2014; Berry et al., 2015). Neumann suggested that Gmed on the WB side must generate a force of at least twice the body weight to maintain correct pelvic and trunk alignment during unilateral WB posture (Neumann, 2017). Nevertheless, previous studies have shown no significant difference in Gmed activity between unilateral WB hip abduction and side-lying hip abduction (Bolgla and Uhl, 2005; Jacobs et al., 2009). These findings may be the result of compensatory movements such as trunk lateral shift caused by pelvic lateral tilt to diminish external moment during WB hip abduction exercises (Bolgla and Uhl, 2005; Krause et al., 2009). Because the trunk (especially the lumbar

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spine) is connected to the pelvis by a kinematic link (Neumann, 2017), lateral pelvic tilt during unilateral WB hip abduction could cause a lateral trunk shift to the WB side. Although subjects in previous studies were instructed to maintain pelvic level and an upright trunk position, the pelvic and trunk positions were not objectively monitored during unilateral WB hip abduction exercises (Bolgla and Uhl, 2005). To explore the effects of unilateral WB hip abduction exercises on Gmed on the WB side, interventions that objectively monitor pelvic alignment are required.

Real-time visual biofeedback (RVBF) has been proposed as an effective intervention for guiding correct posture alignment and improving performance by providing real-time information on body alignment (Anson et al., 2013; Hunt et al., 2014; Nyman and Armstrong, 2015). A previous study by Nyman and Armstrong (2015) showed that RVBF of knee kinematics increased knee flexion and distance between the knees during drop landing, decreasing the risk of anterior cruciate ligament injury. In another report, RVBF of the trunk position decreased trunk translation during treadmill walking (Anson et al., 2013). In addition, angular RVBF was shown to be more effective than mirror and video images in correcting alignment (Hunt et al., 2014).

Based on previous findings (Cynn et al., 2006, Anson et al., 2013; Hunt et al., 2014; Nyman and Armstrong, 2015), RVBF of pelvic movement may be used to correct pelvic alignment when Gmed is activated during hip abduction exercises. To our knowledge, no study has explored how objectively monitored pelvic alignment affects lateral pelvic tilt movement and selective Gmed muscle activation during both unilateral WB and side-lying hip abduction exercises, despite both exercises sometimes being accompanied by compensatory lateral pelvic tilt (Bolgla and Uhl, 2005; Cynn et al., 2006; Krause et al., 2009). Because lateral pelvic tilt can lead to greater QL muscle activation during hip abduction (Cynn et al., 2006; Park et al., 2010) or vice versa, the Gmed/QL activity ratio must be identified to determine the influence of corrective pelvic alignment on selective Gmed muscle activation during hip abduction exercises. Therefore, in this study, we explored the effects of pelvic movement RVBF in the frontal plane on electromyographic (EMG) activity of the Gmed and QL, Gmed/QL activity ratio, and lateral pelvic tilt during unilateral WB and side-lying hip abduction exercises. The characterization of the effects of corrective pelvic alignment using RVBF during unilateral WB and side-lying hip abduction exercises would provide clinicians with useful information when designing exercise programs that enhance selective Gmed activation.

2. Methods

2.1. Participants

Fifteen healthy males (mean age = 23.33 ± 0.82 years; mean height = 172.73 ± 4.33 cm; mean body weight = 73.00 ± 9.15 kg) with no dysfunction of the lower extremities who could perform hip abduction without pain were recruited for this study. Exclusion criteria included a history of surgery or injury of a lower extremity over the past year or increased pain in the lumbar spine, hip, knee, or ankle during the last 2 weeks (Berry et al., 2015; Bolgla and Uhl, 2005). Prior to participation, all participants signed a written informed consent form approved by the Public Institutional Review Board Designated by Ministry of Health and Welfare.

The sample size was calculated based on power analysis using a large effect size ($d = 0.8$). The results indicated that at least 15 participants would be required to detect a difference in Gmed EMG in unilateral WB hip abduction with and without RVBF using a two-tailed test at a power of 80% and a significance level of 0.05.

2.2. Electromyography recording

EMG activity of Gmed and QL on the side of the tested leg was measured using wireless miniDTS sensors (Noraxon, Inc., Scottsdale, AZ, USA) with a common-mode rejection ratio of > 100 dB and noise of < 1 μV. The leg used by the participant to kick a ball was designated the tested leg (Krause et al., 2009; Park et al., 2010). Because no significant difference in hip abductor strength between sides has been reported in previous studies (Mosler et al., 2017; Lopes et al., 2018), hip abduction and outcome measures were performed only on the tested side (Park et al., 2010; McBeth et al., 2012). Two bipolar surface electrodes (Ag/AgCl) with a diameter of 15 mm were placed 2 cm apart on landmarks of each muscle. EMG electrodes were attached along the muscle fiber on the proximal side one-third of the distance between the iliac crest and greater trochanter for Gmed, and approximately 4 cm lateral from the muscle belly of the erector spinae at the mid-point between the iliac crest and 12th rib along the muscle fiber for QL (Park et al., 2010). Prior to EMG electrode attachment, the skin was cleaned using a disposable alcohol swab. EMG signals were collected and analyzed using MyoResearch 3 (MR3) software (Noraxon, Inc.). The sampling rate of raw EMG data was 1500 Hz with a bandwidth of 10–450 Hz. All EMG data were full-wave rectified and converted to root-mean-square (RMS) values using a 125-ms window.

To normalize the EMG data, subjects performed maximum voluntary isometric contraction (MVIC) of each muscle. All MVIC trials were performed using the tested leg for 5 s in the side-lying position. Participants were instructed to abduct the tested leg against manual resistance at the ankle for Gmed MVIC trials and to bring the pelvis up to the ribs with trunk lateral flexion on the tested side against manual resistance at the hip and pelvis for QL MVIC trials (Hislop et al., 2013). The MVIC trials for each muscle were performed twice with a rest period of 1 min between trials, and the mean EMG value of the middle 3 s of two MVIC trials was used to normalize values for each muscle. All EMG data during hip abduction exercises are expressed as percentages of MVIC (%MVIC).

2.3. Lateral pelvic tilt recording

The 4D-MT Motion Sensor (Relive Co., Ltd., Gimhae, South Korea) was used at a sampling rate of 25 Hz to measure lateral pelvic tilt. The 4D-MT Motion Sensor consists of a triaxial gyroscope and an accelerometer. Tilt information from the 4D-MT Motion Sensor in three planes (i.e., sagittal, frontal, and transverse planes) was transmitted in real time to 4D-MT analysis software (Relive Co., Ltd.) on an android tablet PC. The 4D-MT analysis program calculates the tilt angle of the sensor in three planes and shows real-time sensor angles on the tablet PC screen.

In the present study, to measure lateral pelvic tilt during hip abduction exercises, the 4D-MT Motion Sensor was attached on the anterior superior iliac spine on the moving limb side (Fig. 1). We selected ASIS, the most prominent bony landmark of the pelvis, for motion sensor placement, because skin artifact at this landmark has been suggested to be minimal (Schache et al., 2001, 2002). The tilt angle of the sensor in the frontal plane was calculated to measure the amount of

Fig. 1. Motion sensor attachment.

lateral pelvic tilt and provide participants with RVBF of pelvic motion in the frontal plane during hip abduction exercises. The lateral pelvic tilt angle was calibrated to 0° at the starting position of hip abduction exercises with neutral pelvic alignment. To ensure the same starting position, foot placement was marked with tape on the floor and wall before test trials.

2.4. Experimental procedures

After EMG electrodes and motion sensors were attached, all participants performed unilateral WB hip abduction and side-lying hip abduction exercises without RVBF, followed by both hip abduction exercises with RVBF only on the tested side. Under each condition (with or without RVBF), unilateral WB hip abduction and side-lying hip abduction exercises were performed in random order. Because flexion/extension of the hip and knee can influence Gmed and tensor fascia latae muscle activation and vice versa (Sahrmann, 2002; Mascal et al., 2003; Page et al., 2010; McBeth et al., 2012), participants performed hip abduction on the wall without rotation while keeping the knee extended and heel in contact with the wall to prevent compensatory hip and knee movement.

For unilateral WB hip abduction without RVBF, participants stood with feet shoulder-width apart and placed the fingertips of both hands on the table. Participants were then instructed to raise the non-tested leg to 30° of hip abduction to induce unilateral WB on the tested leg (Jacobs et al., 2009) (Fig. 2A). A target bar was used to control 30° of hip abduction during all hip abduction exercises. The height of the target bar was adjusted for each participant. During unilateral WB hip abduction, participants were instructed to maintain balance and upright trunk position using minimal weight support on the table with fingertips (Bolgla and Uhl, 2005; Jacobs et al., 2009). For side-lying hip abduction without RVBF, participants performed 30° of hip abduction using the tested leg in a side-lying position with the tested leg on top (Fig. 2B).

Under RVBF conditions, participants monitored the lateral pelvic tilt angle on the tablet PC screen in real time (Fig. 3A) during unilateral WB hip abduction (Fig. 3B) and side-lying hip abduction (Fig. 3C). The tablet PC screen was placed at eye level in front of the participant, at a distance of 50 cm. Participants were asked to maintain neutral pelvic alignment to the best of their ability by monitoring real-time lateral pelvic tilt angle while performing unilateral WB hip abduction and side-lying hip abduction, as described above. All participants were allowed practice time for 15 min in each hip abduction exercise with RVBF, to gain familiarity with RVBF conditions prior to test trials.

For all hip abduction exercises, participants raised the lower extremity over 3 s until the ankle touched the target bar and then maintained 30° of hip abduction position for 5 s. Hip abduction was repeated three times under each condition. Subjects were allowed rest periods of 1 min between trials and 5 min between conditions.

2.5. Data and statistical analysis

Gmed and QL EMG activity and lateral pelvic tilt angle during each 5 s isometric hip abduction trial were collected, and the mean value of the middle 3 s of each trial was calculated. The mean value of three test trials under each hip abduction exercise condition was calculated for data analysis.

Differences in Gmed and QL EMG activity levels, in the Gmed/QL activity ratio, and in the lateral pelvic tilt between exercises were analyzed using two-way repeated-measures ANOVA, with the biofeedback condition (with and without RVBF) and posture (unilateral WB or side-lying) as the within-subject factors. If significant interaction or main effects were found, *post hoc* analysis using the Bonferroni correction was performed. PASW software ver. 18.0 (SPSS, Inc., Chicago, IL, USA) was used for statistical analyses with an alpha level of 0.05.

3. Results

For Gmed muscle activity, a significant biofeedback-by-posture interaction and a main effect of biofeedback condition were found ($p < 0.05$) (Table 1). *Post hoc* analyses revealed greater Gmed EMG activity during hip abduction with than without RVBF (unilateral WB: $p < 0.001$; side-lying: $p = 0.004$). However, there was no significant main effect of posture on Gmed muscle activity ($p = 0.866$).

There were significant main effects of biofeedback and posture on QL muscle activity ($p < 0.05$), although no significant biofeedback-by-posture interaction was found ($p = 0.741$) (Table 1). *Post hoc* analyses showed significant increases in QL EMG activity during hip abduction with RVBF compared to without RVBF (unilateral WB: $p = 0.006$; side-lying: $p = 0.034$), and QL muscle activity was significantly decreased in unilateral WB hip abduction compared to side-lying hip abduction (without biofeedback: $p = 0.002$; with biofeedback: $p < 0.001$).

Significant biofeedback-by-posture interaction and main effects of both biofeedback and posture conditions were detected in the Gmed/QL activity ratio and in lateral pelvic tilt ($p < 0.05$) (Table 1). The *post hoc* analyses revealed a significant increase in the Gmed/QL activity

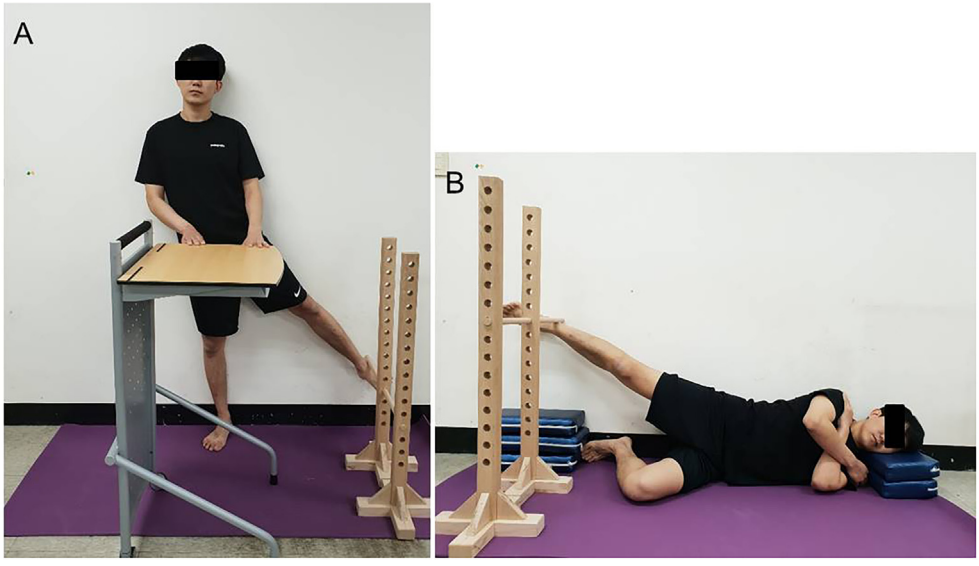

Fig. 2. Unilateral weight-bearing hip abduction (A) and side-lying hip abduction (B) without real-time visual biofeedback.

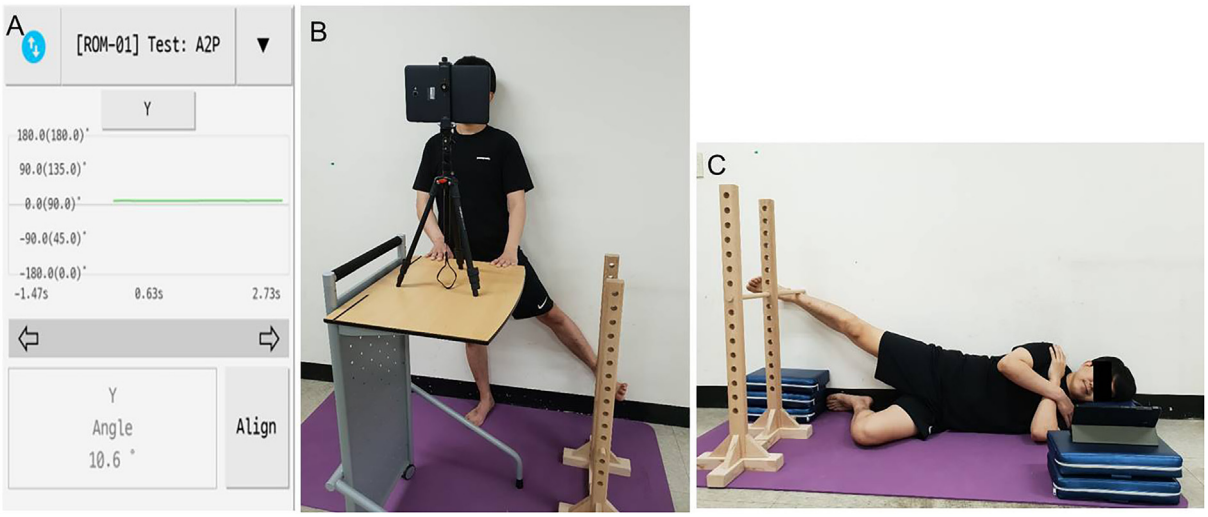

Fig. 3. Real-time lateral pelvic tilt angle (A) is provided for unilateral weight-bearing hip abduction (B) and side-lying hip abduction (C) exercises with real-time visual biofeedback conditions.

ratio during hip abduction with RVBF compared to that without RVBF in unilateral WB hip abduction ($p = 0.027$), but not in side-lying hip abduction ($p = 0.922$), as well as a significant decrease in lateral pelvic tilt during hip abduction with RVBF compared to without RVBF (unilateral WB: $p < 0.001$; side-lying: $p < 0.001$). In addition, significant increases in the Gmed/QL activity ratio (without biofeedback: $p = 0.007$; with biofeedback: $p = 0.001$) and lateral pelvic tilt (without biofeedback: $p < 0.001$; with biofeedback: $p < 0.001$) were observed during unilateral hip abduction compared to side-lying hip abduction.

4. Discussion

The present study showed that application of RVBF to monitor pelvic movement leads to increased EMG activity of Gmed and an increased Gmed/QL activity ratio, together with a greater decrease in lateral pelvic tilt in unilateral WB hip abduction than in side-lying hip abduction.

Our results showed significant biofeedback-by-posture interaction effect on Gmed activation and lateral pelvic tilt ($p < 0.05$). These findings indicate that the change in Gmed muscle activation and lateral pelvic tilt caused by RVBF is greater during unilateral WB hip abduction compared to side-lying hip abduction. During side-lying hip abduction, because the trunk and contralateral lower extremity were supported, increased lateral pelvic tilt may result from uncontrolled pelvic movement caused by hip abduction. For unilateral WB hip abduction, the base of support was provided only by the WB foot. Thus, increased lateral pelvic tilt may also be affected by compensatory movement in response to a shift in the center of mass of the trunk to the WB side to maintain balance and shorten the external moment arm (Bolgla and Uhl, 2005; Jacobs et al., 2009), as well as uncontrolled pelvic movement caused by hip abduction during unilateral WB hip abduction. We observed greater lateral pelvic tilt during unilateral WB hip abduction compared to side-lying hip abduction ($p < 0.05$), which supports our inference. Similarly, it is possible that decreased lateral pelvic tilt reduces the amount of trunk shift, requiring greater Gmed activation to respond to increased external moment during unilateral WB hip abduction. Taken together, these data suggest that RVBF of pelvic movement may decrease lateral pelvic tilt caused by uncontrolled hip abduction movement and also by compensatory trunk shift during unilateral WB hip abduction. This, in turn, contributes to the greater decrease in lateral pelvic tilt and greater increase in Gmed muscle activation when applying RVBF in unilateral WB hip abduction compared to side-lying hip abduction. Changes in the hip abductor internal moment arm may also explain our findings. Given that the hip abductor internal moment arm decreases with decreasing lateral pelvic tilt during unilateral WB (Henderson et al., 2011), a decrease in lateral pelvic tilt may require greater effort by hip abductors, leading to a greater increase in Gmed muscle activity when applying RVBF in unilateral WB hip abduction.

QL EMG activity was increased in side-lying hip abduction compared to unilateral WB hip abduction in this study ($p < 0.05$). Uncontrolled lateral pelvic tilt on the moving limb side is a common faulty movement during hip abduction (Cynn et al., 2006; Page et al., 2010). This uncontrolled lateral pelvic tilt movement could increase QL activation on the moving limb side (Cynn et al., 2006). In this study, QL muscle activation was measured on the WB limb side during unilateral WB hip abduction, whereas it was measured on the moving limb side during side-lying hip abduction. Thus, postural differences between these hip abduction exercises may lead to greater QL EMG activity during side-lying hip abduction compared to unilateral WB hip

Table 1
Statistical data on muscle EMG activity and lateral pelvic tilt.

Measure	Unilateral WB hip abduction		Side-lying hip abduction		*P*		
	Without RVBF	With RVBF	Without RVBF	With RVBF	Interaction	Biofeedback	Posture
Gmed activity (%MVIC)	27.19 ± 10.25	40.11 ± 15.05	31.64 ± 8.15	36.79 ± 10.87	0.015*	< 0.001*	0.866
QL activity (%MVIC)	20.28 ± 10.90	24.23 ± 11.46	32.70 ± 11.72	37.47 ± 9.59	0.741	0.002*	< 0.001*
Gmed/QL activity (ratio)	1.67 ± 0.96	2.08 ± 1.27	1.10 ± 0.59	1.09 ± 0.65	0.026*	0.039*	0.001*
Lateral pelvic tilt (°)	16.07 ± 4.25	12.09 ± 4.02	6.91 ± 2.39	4.86 ± 2.05	0.008*	< 0.001*	< 0.001*

Abbreviations: Gmed, gluteus medius; MVIC, maximum voluntary isometric contraction; QL, quadratus lumborum; RVBF, real-time visual biofeedback; WB, weight-bearing.

* $p < 0.05$.

abduction. In the present study, QL EMG activity increased during unilateral WB and side-lying hip abduction exercises with RVBF compared to trials without RVBF ($p < 0.05$), despite significant decreases in lateral pelvic tilt ($p < 0.05$). These results are inconsistent with previous findings of Cynn et al. (2006), who showed decreased QL muscle activation together with decreased lateral pelvic tilt during side-lying hip abduction with lumbar stabilization. The differences in findings between the present and previous studies may be due to differences in abdominal and trunk muscle contraction strategies to correct pelvic alignment. Co-activation of the abdominal and trunk muscles can influence hip muscle activity during therapeutic hip exercises (Kim and Kim, 2018; Tsang et al., 2018). Although the previous study used an abdominal draw-in maneuver for selective activation of trunk stability muscles (Cynn et al., 2006), participants in the present study were only asked to maintain neutral pelvic alignment when using RVBF and were not instructed to use specific abdominal and trunk muscle contraction strategies. Thus, participants may have used strategies involving co-activation of abdominal and trunk muscles, resulting in an increase in QL muscle activity and a decrease in lateral pelvic tilt during hip abduction exercises with RVBF. Previous studies showed that co-activation strategies of abdominal and trunk muscles increased QL muscle activation and decreased lateral pelvic tilt during side-lying hip abduction (Kim and Kim, 2018), which supports our hypothesis.

Our results showed significant biofeedback-by-posture interactions in the Gmed/QL activity ratio ($p < 0.05$). It has been argued that it is necessary to minimize compensation, such as excessive QL activation, to effectively enhance Gmed (Cynn et al., 2006; Page et al., 2010; Park et al., 2010). Based on our findings, the protocol of facilitating greater Gmed muscle activity than QL muscle activity, such as unilateral WB hip abduction with RVBF, can provide clinicians with useful information when designing an effective Gmed strengthening exercise program. In the present study, RVBF significantly increased the Gmed/QL activity ratio during unilateral WB hip abduction ($p = 0.027$) but not during side-lying hip abduction ($p = 0.922$). With RVBF, the increase in QL muscle activity was similar under unilateral WB (3.95% MVIC) and side-lying (4.77% MVIC) conditions, whereas the increase in Gmed muscle activity was greater for unilateral WB abduction (12.92% MVIC) than for side-lying abduction (5.15% MVIC). This may be because the decrease in lateral pelvic tilt when applying RVBF was greater during unilateral WB hip abduction than during side-lying hip abduction, so greater Gmed muscle activity was required to control pelvic movement during unilateral WB hip abduction. This difference in the increase in Gmed muscle activity with RVBF between both hip abduction exercises may have influenced our findings.

Interactions between RVBF and the movement sequence of the pelvis and hip during anticipatory postural adjustment may also explain our findings. During tasks involving movements of the hip, pelvis, and trunk, the sequence of joint movements influences the peak muscle activation pattern (Cordo et al., 2003; Cordo and Gurfinkel, 2004). During unilateral WB tasks, the center of mass is moved to the supporting limb side by horizontally shifting the pelvis as an anticipatory postural adjustment before foot-off in the moving limb (Tateuchi et al., 2011; Tateuchi et al., 2016). Therefore, it is possible that RVBF reduces the unwanted combination of lateral pelvic tilt and trunk lateral flexion during anticipatory postural adjustment and consequently delays the onset of lateral pelvic tilt during unilateral WB hip abduction, leading to greater changes in lateral pelvic tilt and the Gmed/QL activity ratio in unilateral WB hip abduction. However, the pelvis and hip movement sequence was not measured in the present study. Therefore, the interaction of RVBF and movement sequence during anticipatory postural adjustment must be identified in a future study.

Our findings demonstrate that limited lateral pelvic tilt with RVBF can influence Gmed muscle performance during hip abduction exercises. In particular, intended correction of pelvic alignment has a greater influence on the unilateral WB hip abduction exercise, based on our findings showing greater changes in Gmed activity, Gmed/QL activity ratio, and lateral pelvic tilt. Therefore, when performing hip abduction exercises to strengthen Gmed in the clinical setting or the sports performance training field, RVBF could be useful to minimize compensatory lateral pelvic movement and increase Gmed muscle activity during hip abduction exercises, especially under unilateral WB conditions.

This study has some limitations. First, we did not measure the amount of weight support using fingertips during unilateral WB hip abduction. Thus, the effect of hand support on muscle activity was not characterized in this study. Second, we estimated trunk shift using lateral pelvic tilt; however, trunk kinematics were not directly measured during hip abduction. Third, all participants were asymptomatic young males. Balance strategies and accuracy of vision may vary with symptoms and age; therefore, further study including symptomatic and/or older populations should be performed to generalize our findings. In addition, participants performed hip abduction exercises with the leg that they used to kick a ball. To extend clinical significance of our findings, future studies should examine hip abduction exercises with RVBF using both legs, because leg dominance differs according to the task performed (Van Melick et al. 2017). Finally, we did not completely exclude the influence of skin movements on lateral pelvic tilt angle.

5. Conclusions

Our findings show that RVBF of pelvic movement leads to increased Gmed muscle activation together with a decrease in lateral pelvic tilt during both unilateral WB and side-lying hip abduction exercises. Additionally, increases in Gmed and in the Gmed/QL activity ratio along with a decrease in lateral pelvic tilt associated with RVBF of pelvic movement were greater in unilateral WB hip abduction compared to side-lying hip abduction. These results suggest that RVBF of pelvic movement could be a useful strategy during hip abduction exercises, especially under unilateral WB conditions, when the goal of exercise is to strengthen Gmed.

Declaration of Competing Interest

The authors declared that there is no conflict of interest.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jelekin.2019.06.003.

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