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Full Length Article

The effects of enhanced abdominal activation on quadriceps muscle activity levels during selected unilateral lower extremity exercises

Gulcan Harput[a,*], Mahmut Calık[b], Melek Merve Erdem[a], Nazlı Sarı[c], Sualp Gunduz[a], Nalan Cınar[a]

[a] Hacettepe University, Faculty of Health Sciences, Physiotherapy and Rehabilitation Department, Ankara, Turkey
[b] Uskudar University, Faculty of Health Sciences, Department of Physiotherapy and Rehabilitation, Istanbul, Turkey
[c] Ankara Private Guven Hospital, Ankara, Turkey

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ABSTRACT

The purpose of this study was to investigate the effect of Abdominal Enhancement (AE) on the muscle activation of vastus medialis obliquus (VMO), vastus lateralis (VL) and rectus femoris (RF) muscle activation levels during eccentric, isometric and concentric phases of single leg raise (SLR), single leg wall squat (SLWS) and forward lunge (FL) exercises. Sixteen healthy individuals (Age: 24.6 ± 1.7 years) were included in the study. Internal Obliques/Transversus Abdominis (IO/TA), VMO, RF and VL muscle activation levels were measured by surface EMG during the exercises in two conditions: with and without AE. The abdominal drawing-in technique was used for AE. Repeated-measures analysis of variance was performed for statistical analysis. With AE, the average of IO/TA muscle activation level was 28.9%. VMO and VL muscle activation levels were significantly greater with AE during SLR ($p = .02$), SLWS ($p < .001$) and FL (VMO, $p = .008$, VL, $p = .04$) exercises. The effect of AE on VMO muscle activation level ranged from 2.5% to 5% (Effect size range: 0.54 to 0.91) and VL muscle activation level ranged from 2.1% to 5.5% (Effect size range: 0.35–1.24). RF muscle activation level did not change with AE ($p > .05$). The results of this study showed that AE increased VMO and VL muscle activities during SLR, SLWS and FL exercises but the corresponding changes were small. Even if this is not enough for muscle strengthening, exercises with AE may be used to enhance knee joint stability while controlling lumbopelvic stability.

1. Introduction

Exercise training for quadriceps is the primary goal of the rehabilitation programs for knee joint dysfunctions such as patellofemoral pain, anterior cruciate ligament and meniscus injuries (Barton et al., 2015; Gokeler et al., 2014; Heckmann et al., 2006). There is evidence that shows alterations in quadriceps muscle activation and decrease in strength following knee injuries (Hurley et al., 1994), and decrease in quadriceps function has been shown to be related with alterations in lower extremity kinematics, lower self-reported knee function, and decreased functional performance (Gokeler et al., 2010, 2014; Lepley, Pietrosimone, & Cormier, 2018). Thus, functional lower extremity exercises emphasizing the quadriceps activation are encouraged during the early phases of the knee rehabilitation. However, faulty compensatory movements in lumbopelvic complex such as increased anterior pelvic tilt and lumbar lordosis during these functional exercises may negatively affect the activity of lower limb muscles since they may increase hip

* Corresponding author at: Hacettepe University, Faculty of Physical Therapy and Rehabilitation Department, Sıhhiye 06100, Ankara, Turkey.
E-mail address: gulcan.aktas@hacettepe.edu.tr (G. Harput).

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internal rotation and knee valgus (Powers, 2003). In addition, these compensatory movements may decrease the effectiveness of the exercises and increase the risk of back injury during these exercises (Hoffman, Johnson, Zou, Harris-Hayes, & Van Dillen, 2011; Oh, Cynn, Won, Kwon, & Yi, 2007; Willcox & Burden, 2013; Willson, Dougherty, Ireland, & Davis, 2005). There is a link between the lumbopelvic complex and lower limbs in terms of muscle dysfunction, as show in previous studies. Rahbar, Shimia, Toopchizadeh, and Abed (2015) documented the relationship between low back pain and knee pain and they suggested that lumbar spine should be evaluated in the management of knee pain. Gluteal muscle weakness was also reported in individuals with low back pain (Cooper et al., 2016; Hides, Oostenbroek, Franettovich Smith, & Mendis, 2016).

To achieve neutral lumbar spine alignment and to prevent compensatory lumbopelvic movements during the activities, therapists, trainers, and coaches often teach their clients how to stabilize their spine by using Abdominal Enhancement (AE) techniques (Kisner, 2002). AE, which aims to increase abdominal muscle activation voluntarily, can be achieved by using abdominal bracing or Abdominal Drawing-in (AD) techniques. Abdominal bracing involves global co-contraction of abdominal wall muscles, while AD aims to activate abdominal core muscles including Transversus Abdominis (TA) and Internal Oblique (IO) (Akuthota & Nadler, 2004; Teyhen et al., 2005). Although there is no consensus on which technique is better than the other in terms of lumbopelvic stability (O'Sullivan, Twomey, & Allison, 1998), AD has been effective to retrain altered motor patters in abdominal muscle and increase spinal stability, while AB has been found to be more effective to control spinal displacement against sudden perturbation (Vera-Garcia, Elvira, Brown, & McGill, 2007). AE techniques have shown to modify the activities of the targeted muscles during lower extremity exercises. Previous researchers found that hip muscle activation levels were greater with increased abdominal muscles' co-activation while performing functional lower extremity exercises (Barbosa et al., 2017; Chan et al., 2017; Tsang et al., 2018). Since TA and IO muscles and gluteal muscles are connected through the thoracolumbar fasciae, co-activation of TA and IO increases the intraabdominal pressure and the tension of the thoracolumbar fascia. This mechanism improves the functional kinetic chain movements of the lower limbs by enhancing muscle activation (Sahrmann, 1992). Therefore, Tsang et al. (2018) suggested that increase in the activation of TA and IO muscles may have a potential role in improving the efficacy of gluteal therapeutic exercises.

We were aware of only one study that examined the effect of AE on thigh muscle activation during squats (Barbosa et al., 2017). Barbosa et al. (2017) found that rectus femoris (RF) and biceps femoris activity increased with AD maneuver and Pilates breathing during the descending phase of the squat. They explained that increased muscle activation levels with AE might be due to increase in task awareness. In the literature, there is no study that investigates the effects of AE on quadriceps activation level during unilateral lower extremity exercises. We postulated that performing the functional lower extremity exercises with ensuring lumbopelvic stability via AE would make the exercises safer while enhancing targeted muscle activity. Therefore, the aim of current study was to investigate vastus medialis obliquus (VMO), vastus lateralis (VL) and RF muscle activation levels during eccentric, isometric and concentric phases of single leg raise (SLR), single leg wall squat (SLWS) and forward lunge (FL) exercises with and without AE. It was hypothesized that there would be greater VMO, RF and VL muscle activation with AE during all phases of the exercises.

2. Methods

2.1. Participants

The sample size was calculated using the G-POWER software (Version 3.1.5, Franz Faul, Universitat Kiel, Germany) according to Barbosa et al. (2017) study. A sample size of minimum 11 participants were necessary for achieving 0.90 power considering the effect size of 1.12 between two different conditions (with and without AE).

A total of sixteen healthy individuals (Age: 24.6 ± 1.7 years; BMI: 21.8 ± 2.1 kg/m^2) were included in this study (Table 1). Healthy individuals who were 18–30 years old were included in condition that they had no systemic/neurological problems, no lower extremity injuries at least 1 year and no experience in core stability training. The study was approved by the University Institutional Review Board, and all participants gave informed consent.

2.2. Procedures

2.2.1. Electromyography

A surface EMG system (TELEmyo DTS; Noraxon USA, Inc., Scottsdale, AZ) was used to measure the activation levels of the IO/TA, VMO, VL and RF muscles during the functional exercises. Before testing, the identified locations for surface electrode placement were shaved, abraded, and cleaned using 70% isopropyl alcohol. Bipolar Ag/AgCl surface electrodes were placed at an interelectrode distance of 2 cm. The electrode width was 1 cm; the common-mode rejection ratio was greater than 80 Db, and the input impedance

Table 1
Demographic characteristics of the participants.

Demographic characteristics	Mean ± SD
8 F, 8 M	
Age	24.63 ± 1.67
Height	171.63 ± 10.47
Body mass	65.94 ± 13.65
Body mass index	21.80 ± 2.13

was greater than 10 mΩ. The sampling rate for EMG data was 1500 Hz. Synchronized video capture with a frame rate of 50 frames per second (Logitech C920, USA) was used to determine the different phases of the functional exercises (concentric, isometric, eccentric).

The placement of electrodes for each muscle was done according to SENIAM's European Recommendations for Surface Electromyography (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). The electrodes were placed bilaterally for IO/TA muscles. For VMO, RF and VL muscles, the electrodes were placed only on the dominant limb, which was defined as the leg used to kick a ball.

For the IO/TA, the electrodes were positioned at 2 cm medial to anterior superior iliac spine (ASIS) and beneath a line between two ASISs. For the VMO, the electrodes were placed distally to the anterior superior iliac spine at a mark equivalent to 80% along a line drawn between the anterior superior iliac spine and the medial joint line anterior to the border of the medial collateral ligament. The placement of the electrodes for the VL was at 2/3 on the line from the anterior spina iliaca superior to the lateral side of the patella and for the RF, the electrodes were placed at 50% on the line from the anterior spina iliaca superior to the superior part of the patella. The electrodes were fixed on the skin with double-sided band.

2.2.2. Maximum voluntary isometric contraction testing

Maximum Voluntary Isometric Contractions (MVICs) were recorded before the functional exercises. MVICs were obtained to normalize the EMG data during the exercises.

For the IO/TA MVIC, the participant was in supine with hips and knees flexed 90°, feet were supported, and trunk was maximally flexed and rotated to the right. The examiner applied manual resistance at the shoulders pushing in the trunk extension and left rotation directions (Escamilla et al., 2006; Yoon & Kim, 2013). For the VMO, VL and RF muscle groups, the participants were seated on an isokinetic dynamometer with their hip approximately 90°. Trunk, hip, waist and distal femur on the limb were stabilized by straps. The axis of the dynamometer was aligned to the lateral femoral epicondyle with the dynamometer's laser. The force arm of the dynamometer was secured at 2 cm above the lateral malleolus. Knee flexion angle was set at 60° (Harput, Howard, & Mattacola, 2016). The participants performed three MVICs (each 5-sec duration) for IO/TA and quadriceps muscles with 1-min-rest interval between each MVIC. During the test, the participants were instructed to show their maximum effort against the resistance. Standard verbal encouragement was given for each individual.

2.2.3. Exercises

Single leg raise, single leg wall-squat and forward lunge exercises were selected for functional exercise of the lower extremity.

2.2.3.1. Single leg raise. The participants were positioned supine with the dominant knee fully extended, the ankle dorsiflexed in a neutral position, and the non-dominant knee flexed to 90°. A reference band was placed between two wooden blocks to set the hip flexion to 60° at the end of the SLR. The participants were instructed to lift the limb to the band with 3 s, to lightly touch to the band and to hold the limb at that position during 3 s, and to lower the limb to the table with 3 s (Fig. 1).

2.2.3.2. Single leg wall squat. The participants were instructed to stand on their dominant leg with their hands crossed over their chest and to perform SLWS with 45°of knee flexion while keeping their trunk touch on the wall. The knee flexion angle was adjusted by the band that was placed between parallel columns. The participants were instructed to squat with 3 s, to lightly touch to the band and to hold that position during 3 s and to ascend back to the start position with 3 s. When a participant lost the balance or made contact with the non-dominant leg to the ground, the measurement was repeated (Fig. 2).

Fig. 1. Single leg raise.

Fig. 2. Single leg wall squat.

2.2.3.3. Forward lunge. Forward lunge was performed by positioning the foot of the dominant leg forward a distance equal to a measurement from the greater trochanter to the floor while maintaining a vertical position of their trunk (21). The participants were instructed to flex the dominant leg at 60 knee flexion in 3 s, to lightly touch to the band and to hold that position during 3 s and to return to starting position in 3 s (Fig. 3).

The functional exercises were performed with two conditions: without AE and AE.

2.2.3.4. Abdominal enhancement. According to the previous studies, the participants were taught the AD technique by a physiotherapist (Beith, Synnott, & Newman, 2001; Kim & Kim, 2018; Tsang et al., 2018). The participants were instructed to contract their abdomen as if wearing tight pants and not to hold their breath (Barbosa et al., 2017). Level of the abdominal core activation of the participants was checked by using real-time EMG feedback (TELEmyo DTS; Noraxon USA, Inc., Scottsdale, AZ). The training was performed until the participants reached their ipsilateral (dominant limb side) IO/TA muscle activation to 20% MVIC (Chan et al., 2017) and held that contraction at least 10 s. During the training, the examiner also palpated the rectus abdominis and external oblique muscles to check if the participants recruited these muscles too much during AD technique since targeted muscles were IO/TA muscles. The training took approximately 15–20 min until the participants were able to contract their IO/TA muscles easily in supine and also standing positions.

The pace of the exercises was standardized with the use of a metronome (60 beats/min), and the exercises were divided into 3 phases (concentric, isometric, eccentric) with a synchronized video camera. Each exercise was verbally explained and visually demonstrated by the examiner (MC, MME). All participants performed 3 practice trials for each exercise for exercise familiarization. Then, they performed 3 trials for each exercise. The order of the three functional exercises was randomized within the two experimental conditions. In other words, to make sure that the subjects were naive with regard to the AE technique, the first round of exercises was performed naturally and the second round of exercises was performed with AE.

2.3. EMG signal processing

Electromyographic data processing was accomplished by using Noraxon MyoResearch XP Master Edition software (Noraxon USA, Inc). The EMG signal was bandpass filtered (20–450 Hz), full-wave rectified and smoothed by root mean square moving window

Fig. 3. Forward lunge.
* When compared to neural, VMO and VL muscle activation levels were greater with AE ($p = .02$). However, RF muscle activation did not change with AE ($p = .39$).
Abbreviations; AE, abdominal enhancement; VMO, vastus medialis obliquus; RF, rectus femoris; VL, vastus lateralis.

function with a time constant of 100 milliseconds. For each of the MVIC trial, the maximum value which was obtained over the 5-second maximum effort was recorded, and the average of 3 MVIC trials was used for normalization of the EMG data that were obtained during the exercises. For each trial of each task, the mean signal amplitude of each phase of the task was divided by the MVIC value for each muscle of interest. The average of the trials, expressed as a percentage of MVIC, was used for statistical analysis.

2.4. Statistical analysis

Statistical analyses were performed in IBM SPSS Version 21.0 (IBM Corporation, Armonk, NY). Data were expressed as means and SDs for descriptive data. Normality of EMG data distribution was tested with the Shapiro-Wilk Test. Two-way repeated measures of ANOVA with two within factors (phase by condition) for each exercise and each muscle were performed. A Bonferroni post hoc test was used when a significant interaction and/or main effects were observed. A change in muscle activation level with AE was reported with effect size. Cohen's d-coefficient was used to calculate the magnitude of effect size for all variables. An effect size greater than 0.80 was considered as large; 0.5 to 0.79 as moderate; 0.49 to 0.20 as small; and 0.19 to 0 as negligible (Cohen, 1988). Significance levels were set at $p < .05$.

3. Results

Ipsilateral and contralateral IO/TA activation levels were significantly greater with AE during exercises ($p < .001$) (Table 2). The average ipsilateral IO/TA muscle activation levels with AE ranged from 25.7 to 33% MVIC and contralateral IO/TA muscle activation levels with AE ranged from 22.9 to 39.8% MVIC indicating that the participants achieved targeted AE level during the exercises.

3.1. Single leg raise

There was no significant phase by condition interaction for VMO ($F(2,30) = 1.58$, $p = .222$), RF ($F(2,30) = 0.98$, $p = .386$) and

Table 2
Ipsilateral and contralateral side IO/TA muscle activation levels during concentric, isometric and eccentric phases of single leg raise, single leg wall squat and forward lunge exercises with and without abdominal enhancement.

Exercise	Phase	Side	Without AE (MVIC%)	With AE (MVIC%)	*P* value	Cohen's *d*
SLR	Concentric	Ipsilateral	8.75 ± 5.13	26.49 ± 3.54	< 0.001	3.94
		Contralateral	5.48 ± 3.48	39.82 ± 18.30	< 0.001	2.03
	Isometric	Ipsilateral	11.66 ± 6.56	28.27 ± 5.65	< 0.001	2.69
		Contralateral	26.97 ± 18.45	37.11 ± 16.72	0.034	0.57
	Eccentric	Ipsilateral	12.70 ± 8.46	30.09 ± 5.20	< 0.001	2.34
		Contralateral	27.33 ± 21.45	35.36 ± 16.50	0.032	0.41
SLWS	Concentric	Ipsilateral	8.36 ± 6.16	32.38 ± 9.76	< 0.001	2.79
		Contralateral	8.17 ± 4.71	26.16 ± 11.52	< 0.001	1.79
	Isometric	Ipsilateral	9.05 ± 7.46	33.03 ± 10.00	< 0.001	2.65
		Contralateral	9.44 ± 5.43	31.93 ± 19.15	< 0.001	1.31
	Eccentric	Ipsilateral	7.59 ± 5.09	29.92 ± 9.88	< 0.001	2.60
		Contralateral	9.27 ± 6.86	30.77 ± 17.25	< 0.001	1.42
FL	Concentric	Ipsilateral	6.53 ± 3.67	26.93 ± 6.31	< 0.001	3.72
		Contralateral	7.44 ± 3.87	28.64 ± 11.14	< 0.001	2.17
	Isometric	Ipsilateral	6.23 ± 3.63	25.70 ± 2.81	< 0.001	5.95
		Contralateral	6.64 ± 3.44	22.92 ± 4.20	< 0.001	4.21
	Eccentric	Ipsilateral	5.89 ± 2.13	27.50 ± 4.72	< 0.001	5.29
		Contralateral	6.31 ± 3.07	31.81 ± 12.03	< 0.001	2.36

Abbreviations; AE, abdominal enhancement; SLR, single leg raise; SLWS, single leg wall squat; FL, forward lunge.

VL ($F(2,30) = 1.33$, $p = .279$) activation levels.

Main effect of condition was found significant for VMO ($F(1,30) = 6.58$, $p = .022$) and VL ($F(1,30) = 7.12$, $p = .018$) muscle activation levels. When compared to without AE condition, VMO and VL muscle activation levels were greater with AE (VMO: p = .022, ES: 0.57; VL: p = .018, ES: 0.72). However, RF muscle activation did not change with AE ($p = .389$) (Fig. 4).

3.2. Single leg wall squat

A significant phase by condition interaction was observed for VMO ($F(2,30) = 3.68$, $p = .038$) and VL($F(2,30) = 3.39$, $p = .043$) muscle activation levels. With AE, VMO and VL activation levels were greater during eccentric (VMO: $p = .004$, ES: 0.91; VL:

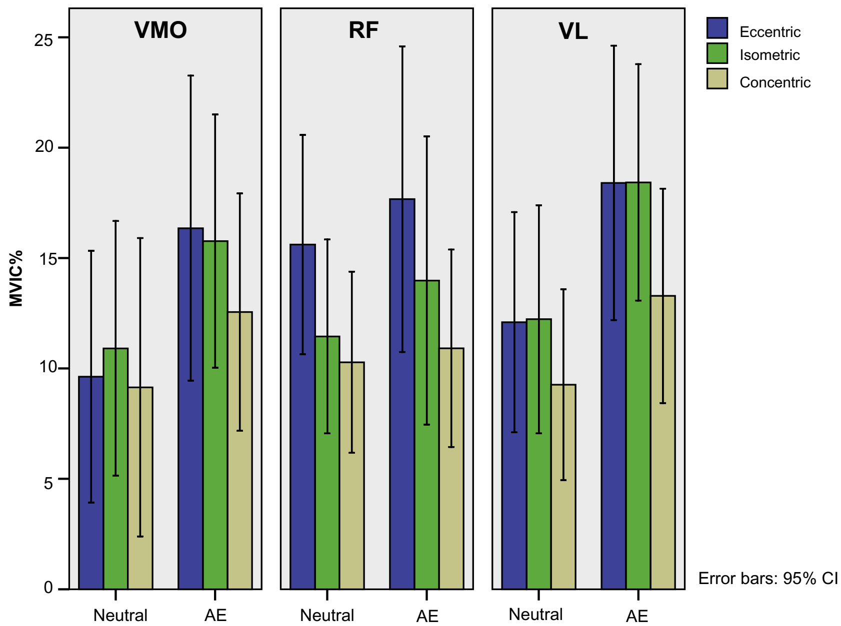

Fig. 4. Vastus medialis obliquus, rectus femoris and vastus lateralis muscle activation levels during single leg raise exercise with and without abdominal enhancement.
* When compared to neural, VMO and VL activation levels were greater during descending and ascending phase of the SLWS (VMO:$p = .004$, $p = .03$; VL: $p = .003$, $p = .04$).
Abbreviations; AE, abdominal enhancement; VMO, vastus medialis obliquus; RF, rectus femoris; VL, vastus lateralis.

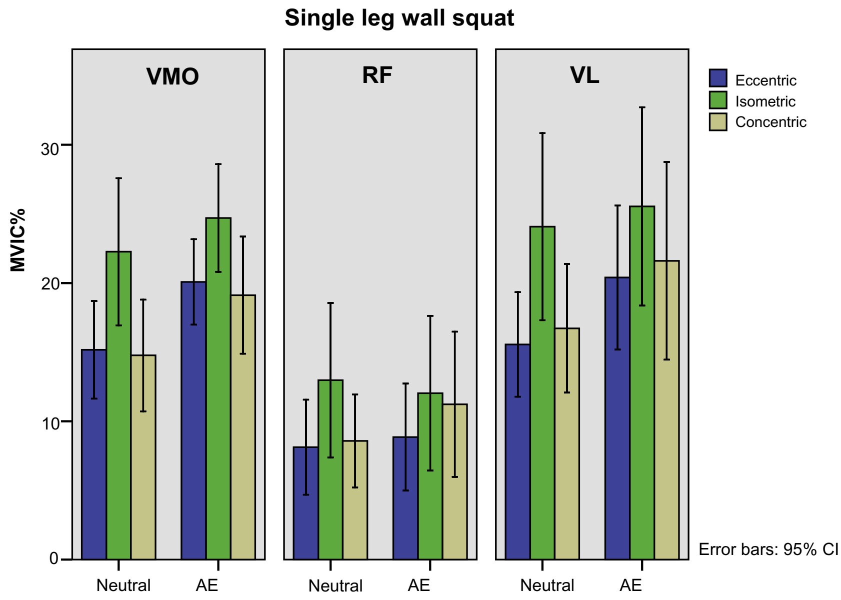

Fig. 5. Vastus medialis obliquus, rectus femoris and vastus lateralis muscle activation levels during single leg wall squat exercise with and without abdominal enhancement.
* When compared to neural, VMO and VL muscle activation was greater with AE (p = .008 and p = .04).
Abbreviations; AE, abdominal enhancement; VMO, vastus medialis obliquus; RF, rectus femoris; VL, vastus lateralis.

p = .003, ES: 1.24) and concentric phase of the SLWS (VMO: p = .028, ES: 0.63; VL: p = .044, ES: 0.52) but it did not change during isometric phase of the SLWS when compared to without AE condition (p > .05). In addition, RF activation level did not change with AE during SLWS (p = .754) (Fig. 5).

3.3. Forward lunge

There was no significant phase by condition interaction for VMO (F(2,30) = 0.11, p = .897), RF (F(2,30) = 2.04, p = .148) and VL (F(2,30) = 1.61, p = .216) muscle activation levels.

A main effect of condition was significant for VMO (F(1,30) = 9.25, p = .008) and VL (F(1,30) = 4.78, p = .044) activation levels. VMO and VL muscle activation was greater with AE when compared to without AE condition (VMO: p = .008, ES: 0.54 and VL: p = .044, ES: 0.35). RF muscle activation did not differ according to AE (p = .177) (Fig. 6).

4. Discussion

This study investigated the effects of abdominal enhancement on VMO, RF and VL activation levels during functional lower extremity exercises. The findings of the present study demonstrated that AE at an average of 29% MVIC increased VMO and VL muscle activation levels during SLR, SLWS, and FL compared to without AE condition. SLWS was the only exercise where AE affected the VMO and VL activation levels by phases. Performing the exercises with AE had no effect on RF muscle activation levels, so we could not completely support the hypothesis of the present study.

SLR, SLWS, and FL exercises that were selected for the present study are the most commonly prescribed exercises in the knee rehabilitation program to improve the quadriceps function (Ayotte, Stetts, Keenan, & Greenway, 2007). Trunk control is one of the key points while performing those exercises since compensatory lumbopelvic movements are commonly observed (Kibler, Press, & Sciascia, 2006). Previous studies demonstrated that 10–20% MVIC of IO/TA was optimal in maintaining the lumbar spinal stability (Stokes & Gardner-Morse, 2003; Stokes, Gardner-Morse, & Henry, 2011). We found that ipsilateral IO/TA muscle activation levels ranged from 6% to 13% MVIC during the exercises that may not be enough for trunk control. With AE, IO/TA activation levels increased up to 29% MVIC on average. From our clinical experiences, the patients or clients found the exercises harder and felt their quadriceps worked more when AD technique was combined with functional knee exercises. Therefore, we planned this present study to see if AE via AD technique would increase quadriceps activity during the exercises. What we found was average of 29% MVIC of abdominal core activation increased VMO and VL muscle activation levels during the SLR, SLWS and FL exercises in healthy individuals. An adequate level of abdominal activation for trunk control may have resulted in performing the exercises properly which may improve the exercises' efficacy on quadriceps activation, but clinical trials should be performed to verify the contribution to rehabilitation programs.

There are some possible explanations for our findings. First, as explained by previous researches (Barbosa et al., 2017; Wells, Kolt, & Bialocerkowski, 2012), increased co-activation of abdominal core muscles may increase the stability function of the lower limb

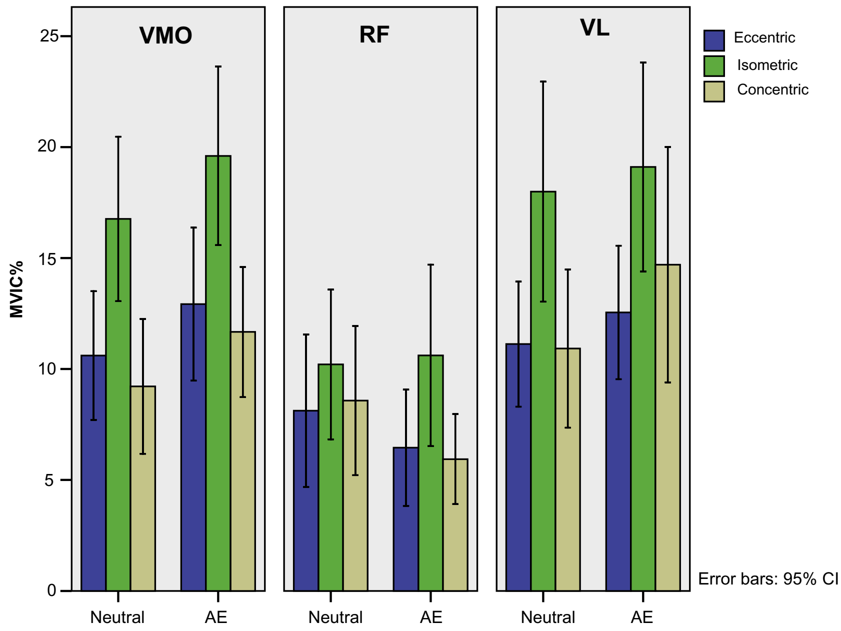

Fig. 6. Vastus medialis obliquus, rectus femoris and vastus lateralis muscle activation levels during forward lunge exercise with and without abdominal enhancement.

muscles that may be related to increased muscle activation levels. As the participants in the present study were instructed to perform each phases of the exercises while keeping abdominal core activity in targeted level (at least 20% MVIC), it may also help to promote the quadriceps activity to control lower limb in standardized pace during the exercises. Due to interlink between lumbopelvic complex and lower extremity, muscle activation and force may transfer from core to lower extremity (Farrokhi et al., 2008; Kibler et al., 2006; Sahrmann, 1992), and minimizing the compensatory lumbopelvic movement with AE may lead quadriceps work more efficiently and isolated during the exercises.

Second, changes in pelvic tilt movement may increase hamstring quadriceps co-activation level. Oh et al. (2007) showed that anterior pelvic tilt decreased from 10 to 3 degrees with AD technique during prone hip extension exercise. Thus, the decrease in the anterior pelvic tilt with AD may increase hamstring activity and relatively greater activity of VMO and VL may be required performing the exercises against increased hamstring activity (Bryanton, Carey, Kennedy, & Chiu, 2015; Elias et al., 2011). Contrary to our hypothesis, RF muscle activity did not change with AE. Considering the most active muscle during SLR exercise (Soderberg & Cook, 1983), we expected to see an increase in RF muscle activity with AE, especially during SLR exercises. RF activity increases with anterior pelvic tilt as it shortens RF muscle length (Workman, Docherty, Parfrey, & Behm, 2008), so decreasing anterior pelvic tilt with AE may compensate the improvement in RF activity that was seen in VMO and VL. Similar to our finding, Barbosa et al. (2017) found no change in RF muscle activity with AD technique during 60-degree- squat exercise. However, they demonstrated that AD combined with pilates breathing increased RF muscle activity in squat exercise and they suggested that these combined activities increased awareness during the exercise.

Previous studies suggested that muscular activation levels ≥40% MVIC are required for muscle strength gains (Andersen et al., 2006; Escamilla et al., 2010). The exercises that were selected for the present study resulted in quadriceps activity less than 30% MVIC with AE (Figs. 4–6). Therefore, these exercises may be useful in the earlier stages of knee rehabilitation or training to improve motor control, especially in individuals who may have relative weakness of the quadriceps following an injury or surgery. VMO muscle activation changed from 10 to 15% MVIC in SLR, 18 to 21% in SLWS and 12 to 15% in FL. Similarly, VL muscle activation level changed from 11 to 17% MVIC in SLR, 10 to 23% in SLWS and 13 to 15% in FL exercises. When evaluating the change in muscle activation levels with AE which generally ranged from 2% to 7% on average, AE might not be efficient to overload the quadriceps to lead strengthening. However, these small changes in muscle activation levels might have an important role to improve the knee joint stability. Therefore, instead of muscle strengthening, AE can be used to contribute knee joint stability by enhancing quadriceps activation while controlling lumbopelvic stability.

We also divided the exercises into different phases such as eccentric, isometric and concentric to see if changes in quadriceps activation levels with AE were related to phases. The findings of Tsang et al. (2018) study showed that changes in gluteal muscle activation levels with AE depended on the phases of the exercises. However, it is not clear why the increase in hip muscles activities with AE differed among phases in their study. We found only the phase effect on VMO and VL activation levels during SLWS with AE. Compared to static phase (isometric), VMO and VL activation levels were greater with AE during eccentric and concentric phases of the SLWS. In addition, the greatest change with AE was seen in VMO and VL muscle activation levels during eccentric phase of SLSW. This finding suggested that AE could be more effective to improve quadriceps muscle activity especially during eccentric phase compared to concentric and isometric phases. Single leg squat exercises are commonly used for evaluating the dynamic control of lower limb. Controlling the lumbopelvic complex posture with AD maneuver during the SLWS might eliminate compensatory trunk movements which might enhance quadriceps muscle activity and knee joint stability. AE also led to remarkable VMO and VL muscle activation changes during SLR exercises even if VMO and VL muscle activation levels seem lower in this exercise compared to SLWS and FL exercises. Considering that SLR is the most commonly used exercise in the acute phase of knee rehabilitation, AE may be beneficial to improve the effectiveness of this exercise. On the other hand, AE technique may not be effective in FL exercise since it leads to smaller changes in muscle activation levels.

This study has several limitations. First, the clinical implication of the present findings might be limited as they reflect the healthy individual's results. Abdominal enhancement may result in different quadriceps muscle activation levels during selected exercises in patient population. Second, the results of this study might be related to AD maneuver performed at an average of 29% of MVIC. The results may be different with “abdominal bracing” technique. Last, this study investigates the acute effect of abdominal enhancement technique in quadriceps muscle activation levels, future studies are needed to investigate the long term effect of abdominal enhancement training on quadriceps muscle activity during therapeutic exercises.

5. Conclusion

The results of this study showed that AE increased VMO and VL muscle activities during SLR, SLWS and FL exercises but the corresponding changes were small. Even if this is not enough for muscle strengthening, exercises with AE may be used to enhance knee joint stability while controlling lumbopelvic stability. This information may help trainers or physiotherapists to design exercises program for quadriceps activation in earlier phases of knee injuries. However, future studies are needed to demonstrate the therapeutic effect of exercises with abdominal enhancement technique in patient population.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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