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Trunk muscle activity during trunk stabilizing exercise with isometric hip rotation using electromyography and ultrasound

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ABSTRACT

Introduction: The purpose of this study was to clarify the muscle activation during trunk stabilizing exercise with isometric hip rotation in healthy males by comparing that with abdominal crunch (AC) and active straight leg raise (ASLR). Electromyography and ultrasound imaging were used to simultaneously measure muscle activity and thickness of the internal oblique (IO), the external oblique (EO), transverse abdominis (TrA) and multifidus (MF) on the right side during exercise.
Methods: Twenty healthy participants performed the following exercises in supine position: isometric right or left hip internal/external rotation, AC, and ASLR. Muscle activity was normalized to maximum voluntary contraction (MVC), and muscle thickness was normalized to resting muscle thickness.
Results: Muscle activation and thickness of IO, MF and TrA increased significantly during the isometric hip rotation compared with other exercises. Muscle activation during the trunk stabilizing exercise with ipsilateral isometric hip internal rotation was 21% in IO, 26% in MF, and with ipsilateral hip external rotation was 12% of MVC in EO.
Conclusion: These findings suggest that trunk stabilizing exercise with isometric hip rotation exercise may be a more safe and effective exercise to promote trunk muscle activity than AC and ASLR. These findings would be beneficial for therapists engaged in prevention and treatment of low back pain.

1. Introduction

Stability of the trunk is necessary during walking and various activities of daily life. Core muscles, including the internal oblique (IO), transverse abdominis (TrA) and multifidus (MF), play important roles in stabilizing the trunk (Stokes et al., 2011). The IO and TrA attach to the spinal vertebrae via the thoracolumbar fascia and contribute to trunk stability by increasing stability of the spinal column (Bergmark, 1989). For instance, activities of IO and MF are higher than of the rectus abdominis (RA) during walking (Arshad et al., 2018; Hanada et al., 2011). A previous study examined the contribution of abdominal muscles to dynamic spinal stability by biomechanical model simulation, and reported that IO was the most important to stability, followed by the external oblique (EO) and RA (Grenier and McGill, 2007). Therefore, coordinated activities of IO and MF are necessary to maintain proper spinal alignment during dynamic activity.

Weakened core muscles lead to instability of the spine and is related to increased load on the spine and to low back pain (LBP). Compared to healthy subjects, LBP patients have significantly smaller IO, EO, TrA, and MF muscles (Goubert et al., 2016). A systematic review showed that chronic LBP is associated with atrophy of MF (Goubert et al., 2016). Thus, trunk training is used for prevention and treatment of LBP (Kim et al., 2013; Lehman et al., 2005; Van Tulder et al., 2000). Various exercises such as abdominal crunch (AC), AC with twist, active straight leg raise (ASLR), and drawing-in maneuver have been used to train the trunk muscles in clinical practice or for health promotion (Park et al., 2013; Teyhen et al., 2009, 2008). However, these exercises do not effectively induce co-contraction of core muscle required for trunk stabilization. Although commonly used as a trunk-strengthening exercise, AC activates RA but not EO and IO (Vera-Garcia et al., 2000), and there is concern that it causes spinal circumferential stress due to it increased compression force on the spine (McGill, 2010). The drawing-in maneuver does not induce contraction of EO and IO due to the lack of a trunk rotating element (Teyhen et al., 2009). An exercise that leads to coordinate activation of trunk muscle would be appropriate for trunk training intended to improve trunk function.

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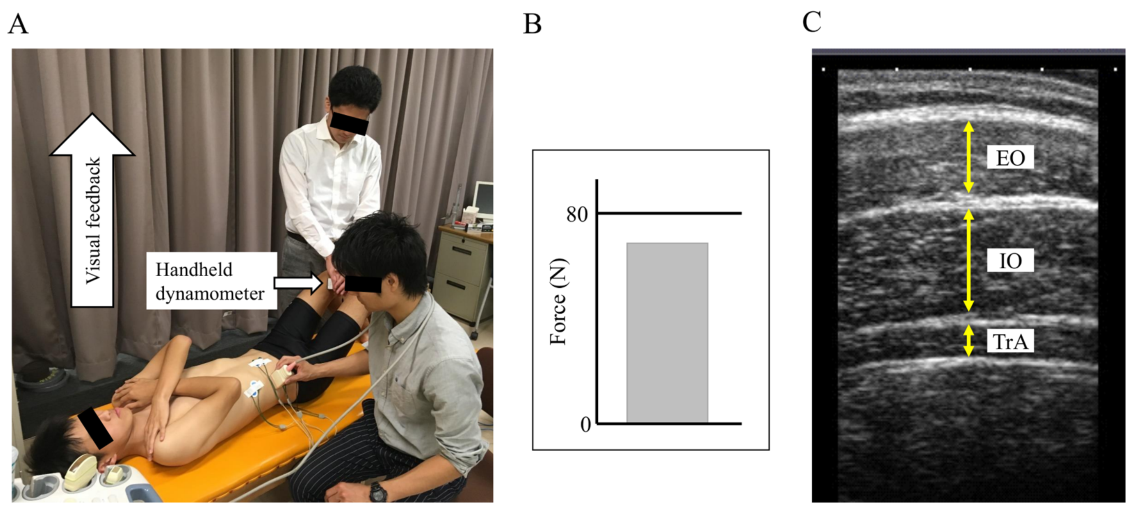

Fig. 1. Measurement of electromyography and ultrasonography during trunk stabilizing exercise with isometric hip internal rotation (A). Rotational force of hip was measured by handheld dynamometer, and displayed as a bar graph above the subject (B). The subject adjusted their output according to visual feedback. Ultrasound image of the lateral abdominal wall during exhalation at rest (C), showing external oblique (EO), internal oblique (IO) and transverse abdominis (TrA) from the top, excluding fascia. Muscle thickness was measured along the center line of the image.

Trunk muscles contract coordinately to stabilize the limbs or to counterbalance external load on limbs in activities that are part of daily life. Studies describing exercises of the lower or upper limbs, such as ASLR (Park et al., 2013), hip joint adduction (Kim et al., 2016) and shoulder horizontal extension (Lee et al., 2013), show that load to unilateral lower limb or upper limb induce activation of abdominal oblique muscle to counter the rotational force. Trunk stabilizing exercises that counter the load leading to unilateral hip internal or external rotation without trunk motion may effectively induce coordinate contraction of core muscles. However, no studies have analyzed muscle contraction during trunk muscle exercise using isometric hip joint rotation in supine position.

The purpose of this study was to clarify the muscle activation in healthy volunteers during a trunk stabilizing exercise counter to the unilateral isometric hip joint internal and external rotation in supine position. The observed muscle activation was compared with that seen during AC and ASLR, exercises generally used for trunk muscle training in a similar position. Surface electromyography (EMG) and ultrasound image (USI) were used together to observe the surface and deep abdominal muscles in this study. We simultaneously measured the muscle activation of RA, IO, EO, and MF using EMG, and the changes in muscle thickness of IO, EO, and TrA using ultrasonography. We hypothesized that, in contrast to AC and ASLR, unilateral isometric hip rotation induces activities of IO, TrA, and MF, as means of promoting trunk stability to counter the exertion of unilateral hip rotational force.

2. Methods

2.1. Subjects

Twenty healthy male volunteers participated in this study (age, 23.3 ± 2.1 years; height, 172.6 ± 6.7 cm; weight, 62.1 ± 7.8 kg). The inclusion criteria were no previous or current neurological, musculoskeletal, or psychological pathology that could influence exercise performance. Prior to the experiment, the exercise protocols were explained to all subjects and they signed an informed consent form approved by the Ethics Committee on Epidemiological Studies at Kagoshima University (No 170116 Epi). The sample size was calculated according to a previous report that compared the IO muscle activity during ASLR using G*Power 3.1.9.2 (Park et al., 2013). The power analysis indicated that at least 17 participants were required to achieve a power of 0.80 at $p < 0.05$.

2.2. Exercise conditions

Muscle activity and thickness on the right side were measured at the same time during seven exercises using EMG and USI data, including AC, ipsilateral and contralateral ASLR, and trunk stabilizing exercise with ipsilateral and contralateral hip internal and external rotation. Muscle activity and thickness during exercises were compared transversely. Before measurement, each subject practiced isometric hip joint internal and external rotation, AC and ASLR for 10 min under the guidance of an experienced therapist. We used a random number table created with Microsoft Excel to randomize the test order. All exercises were performed in the supine position with arms across the chest, to prevent pushing the ground with their hands. Subjects were instructed not to hold their breath while exercising. Each exercise was held for 8 s under isometric contraction and repeated three times. Each subject had a 30 s rest time between trials and a 2 min rest time between test conditions to prevent muscular fatigue.

For trunk stabilizing exercise with isometric hip internal and external rotation, the subject was instructed to maintain the supine position with knees bent at 90°, and maintain the neutral position of the spine and pelvis, excluding compensatory motion other than stabilizing muscle (Suni et al., 2006). Participants tilted exercising leg inward or outward with hip internal or external rotation. Although those exercises were accompanied with hip adduction or abduction, we emphasized the hip rotation by the instruction to keep the feet together during trunk stabilizing exercise (Augustsson, 2016; Macadam et al., 2015; Tsang et al., 2018). The therapist applied a load on the inside or outside of the subject's knee with a handheld dynamometer (Fig. 1A). The loading amount of 80 N was set so that participants could perform rotation inside and outside of the hip joint without compensatory movements, as determined by our preliminary trials. Analog output from handheld dynamometer was sampled at 1000 Hz using a 16-bit A/D converter (NI USB-3643, National Instruments, Austin, TX, USA). A projector showed the force measured by handheld dynamometer on the ceiling in real-time and participants were instructed to match their output force to 80 N for 8 s in this visual feedback condition (Fig. 1B).

The AC was performed in a position similar to the trunk stabilizing exercise. The subjects raised their head and shoulders upwards until the shoulder blades cleared the table, and held this position for 8 s (Teyhen et al., 2008). For the ASLR, the subjects were instructed to be in a supine position with the torso and lower limbs being linear, and to raise their unilateral leg to reach the target bar set at 20 cm above the mat, and to maintain this posture for 8 s (Mens et al., 1999; Park et al., 2013).

2.3. Procedure and data processing

Muscle activation was collected using a Myosystem 1200 s (Noraxon Inc., Scottsdale, AZ, USA), with a frequency response of 10–500 Hz, differential input impedance greater than 10MΩ, a common mode rejection ratio of greater than 100 dB at 50/60 Hz, a gain of 1000, and a sampling frequency of 1000 Hz. The EMG signal was also sampled using the A/D converter. Prior to attaching the electrode, the attachment area was shaved and washed with alcohol-soaked cotton and polished to minimize skin impedance. Electrodes (Blue Sensor M–00–S, Medicotest, Olstykke, Denmark) were placed along the line of RA, EO, IO and MF on the right side with 2 cm inter-electrode distance. The electrodes were placed proximally 2 cm lateral to the umbilicus for RA (Stevens et al., 2006), on 2 cm inferomedial to the anterior superior iliac spine for IO, on inferior edge of the eighth rib superolateral to the costal margin for EO and on the line from caudal tip posterior spina iliaca superior to the interspace between L1 and L2 at the level of L5 spinous process for MF (Cram et al., 1998; SENIAM).

Data measurement and processing for EMG was performed by Matlab 2017 (Mathworks Inc, Natick, Massachusetts, USA). The middle five seconds of the 8 s EMG recording in each exercise were band-pass filtered between 50 and 500 Hz and full-wave rectified, and then the integrated EMG per second was calculated. The integrated EMG was normalized to the maximum EMG obtained during maximum voluntary contraction (MVC) according to the manual muscle test method and expressed as a percentage of MVC (%MVC) (Kendall et al, 2005). The average %MVCs for each exercise were used as representative data for analysis.

The muscle thickness was measured by ultrasonography (NEMIO SSA-550A, Toshiba Medical System Corporation, Tokyo, Japan) with a 38-mm linear transducer (7.5 MHz) in B-mode. The entire USI procedure was conducted by a single author (YN). The operator was licensed physiotherapist for more than 10 years and was sufficiently trained for operational reliability to be high (Ferreira et al., 2011). The transducer was always placed on the lateral wall of the abdomen, perpendicular to the longitudinal axis of the body, 2.5 cm anterior to the midpoint between the iliac crest and the lower edge of the 11th rib (Critchley, 2002; Teyhen et al., 2007). The transducer was placed when in the relaxed supine position and the body surface marked with a pen so that its position did not shift. The participant was instructed to breathe normally in all conditions, and USI was recorded at the end of each expiration. Prior to the measurement of exercise, USI was recorded in a relaxed supine position.

The muscle thickness was measured at the center of the USI along the short axis of the muscles using Image J 1.51 (National Institutes of Health, MD, USA) (Hides et al., 2007). Thickness was estimated as the distance between the inside edge of each border of the muscle fascia according to a previous study (Fig. 1C) (Whittaker et al., 2013). Muscle thickness during exercise was expressed as percentage of that at relaxed supine position (thickness during exercise/thickness at rest × 100) according to a previous study (Miura et al., 2014).

2.4. Statistical analysis

Before the statistical test, EMG and USI reproducibility were assessed by intraclass correlation coefficients ($ICC_{1,3}$) based on data collected during ipsilateral and contralateral ASLR. The measurement accuracy was tested by the standard error of measurement ($SEM = SD \times \sqrt{1 - ICC}$), where SD is standard deviation, and the minimal detectable change using a 95% confidence interval ($MDC_{95} = 1.96 \times \sqrt{2} \times SEM$) (Miura et al., 2014). The $ICC_{(1,3)}$ of EMG of four muscles during ASLR were in the range of 0.871–0.985 ($p < 0.001$; 95% CI, 0.730–0.993), SEMs were 0.50–1.58%, and MDC_{95} were 1.40–4.39% MVC for four muscles. Similarly, $ICC_{(1,3)}$ of normalized muscle thickness was 0.844–0.921 ($p < 0.001$; 95% CI, 0.675–0.966), SEMs were 2.87–5.66% for three muscles, and MDC_{95} were 8.34–9.33% for IO, 7.96–11.83% for EO and 11.80–15.68% for TrA. Reliability of normalized muscle thickness measurement was similar to previous reports analyzing that during ASLR (Koppenhaver et al., 2009; Linek et al., 2015; Teyhen et al., 2009).

The collected data were checked by Shapiro Wilk test to determine if they were normally distributed; then repeated measures analysis of variance if normally distributed, and Friedman test if not normally distributed, was used for analyzing the difference in muscle activation for the seven exercises. Tukey's test or Wilcoxon rank sum test with p-values adjusted by Holm's method were carried out post hoc if necessary. Statistical analysis was performed using R-2.8.1 (The R Foundation for Statistical Computing, Vienna, Austria) with significance level $p < 0.05$.

3. Results

3.1. Muscle activation

The normalized EMG value of the IO was the highest among the seven exercises in the ipsilateral hip internal rotation, 20.8 ± 11.6% MVC, followed by the contralateral hip external rotation, 13.7 ± 9.0%, and AC with 10.7 ± 5.8% MVC ($\chi^2 = 53.0$, $p < 0.001$, Fig. 2A, Table 1A). The EO presented significantly higher activation in the ipsilateral hip external rotation and the contralateral hip internal rotation, 11.6 ± 9.2% and 11.2 ± 9.1%, respectively ($\chi^2 = 54.6$, $p < 0.001$, Fig. 2A, Table 1B). The highest activation of RA was for AC with 17.2 ± 7.3%, but there was low activation, 3% or less, in other exercises ($\chi^2 = 47.9$, $p < 0.001$, Fig. 2A, Table 1C). The MF activity was significantly higher in the ipsilateral hip internal rotation, 25.7 ± 13.4%, and in the contralateral hip external rotation, 22.8 ± 12.5%, followed by the contralateral hip internal rotation, 17.3 ± 10.2%, and ipsilateral hip external rotation, 15.5 ± 8.0% ($\chi^2 = 84.9$, $p < 0.001$, Fig. 2A, Table 1D).

3.2. Muscle thickness

The IO muscle thickness measured using USI was largest during the internal rotation of the ipsilateral hip, 142.4 ± 16.5%, followed by the contralateral hip external rotation with 131.4 ± 17.0% and AC with 115.9 ± 11.6% ($F_{(3.8,72.4)} = 37.1$, $p < 0.001$, Fig. 2B, Table 2A), similar to the IO muscle activation results. The EO muscle thickness showed significant differences among each exercise, however, the change caused by exercise was < 10% ($\chi^2 = 35.1$, $p < 0.001$, Fig. 2B, Table 2B). The TrA muscle thickness was greatest in the ipsilateral hip internal rotation, 144.5 ± 27.4%, then 129.2 ± 25.7%, 118.1 ± 30.7% and 110.9 ± 11.9% for contralateral hip external and internal rotations and AC, respectively ($\chi^2 = 48.0$, $p < 0.001$, Fig. 2B, Table 2C). The TrA muscle thickness across all exercises was similar to that of IO.

4. Discussion

We investigated the activation of core muscles during trunk stabilizing exercise with unilateral isometric hip rotation in the supine position using EMG and USI. Consistent with our hypothesis, during trunk stabilizing exercise with isometric hip rotation there was greater coordinated activation of EO, IO, TrA and MF than during AC and ASLR. The changes caused by exercises to muscle activation measured by EMG and muscle thickness measured using USI showed similar tendencies to each other. These results suggest that trunk stabilizing exercise with isometric hip rotation may be a safe and effective exercise to promote trunk muscle activity.

Muscle activation during the trunk stabilizing exercise with

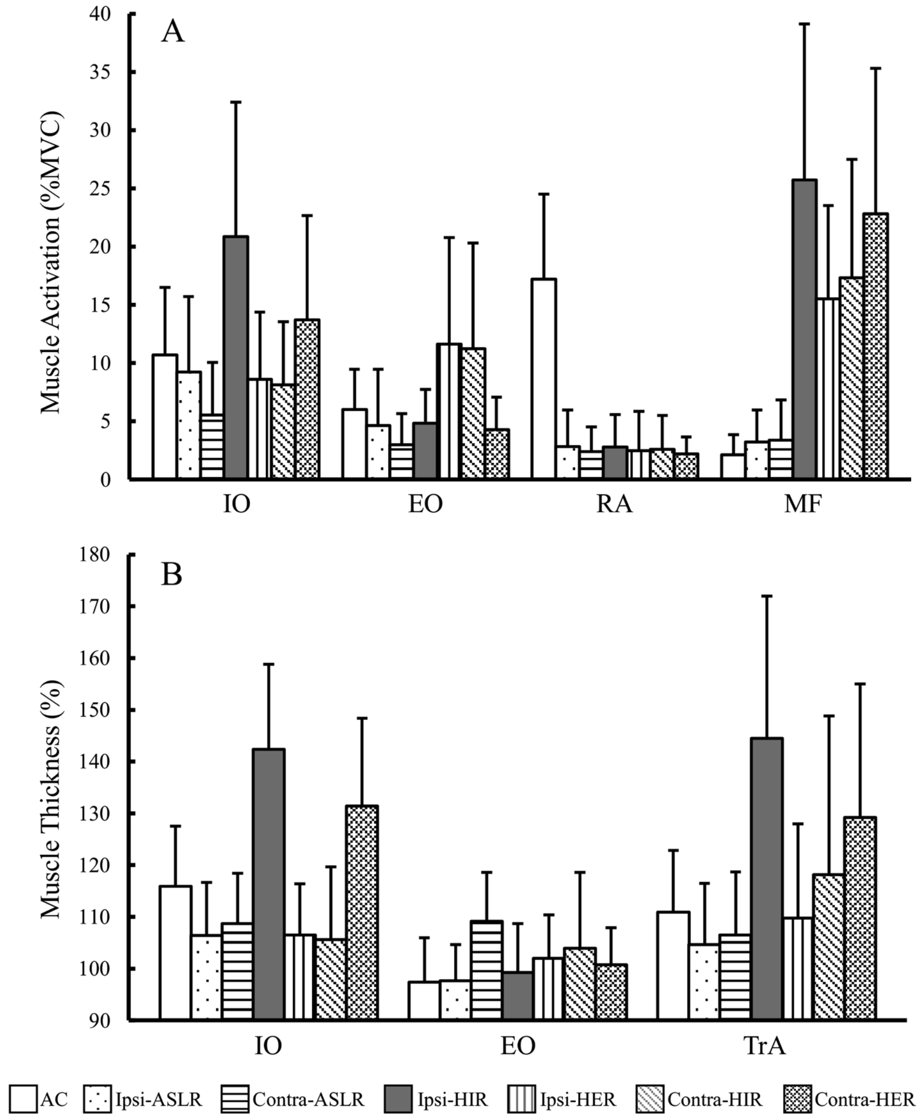

Fig. 2. Comparison of muscle activity and muscle thickness. (A) Muscle activity as a percentage of maximum voluntary contraction (%MVC; mean ± SD). (B) Muscle thickness as a percentage relative to rest. Abbreviations: IO, internal oblique; EO, external oblique; RA, rectus abdominis; MF, multifidus; TrA, transverse abdominis; AC, abdominal crunch; Ipsi-ASLR, ipsilateral-active straight leg raise; Contra-ASLR, contralateral-active straight leg raise; Ipsi-HIR, ipsilateral hip internal rotation; Ipsi-HER, ipsilateral hip external rotation; Contra-HIR, contralateral hip internal rotation; Contra-HER, contralateral hip external rotation.

ipsilateral isometric hip internal rotation was 21% in IO, 26% in MF, and with ipsilateral isometric hip external rotation was 12% of MVC in EO. Activations of core muscle and EO during the trunk stabilizing exercise were greater than during AC and ASLR. As expected, AC increased activity of only the RA and ASLR caused only slight activation of abdominal muscles. A previous study reported increased muscle activation caused by AC of 17.2% in RA, 10.7% in IO and 6.0% in EO – similar to this study (Vera-Garcia et al., 2000). Because AC and ASLR are sagittal plane exercises, they activated RA but no other muscles. Previous studies suggested that increasing RA activity may not be beneficial for stabilizing the lumbar spine (Richardson et al, 1990; Marshall and Murphy, 2005).

Muscle activation and muscle thickness of IO and TrA increased simultaneously in ipsilateral hip isometric internal rotation and contralateral hip external rotation during trunk stabilizing exercise. A previous study reported that IO and TrA muscle thickness measured by USI was significantly correlated with muscle activation measured by EMG (Hodges et al., 2003). Thus, the muscle thickness of IO and TrA measured by USI correctly reflected the degree of muscle activation in the present study. The IO links the pelvis and thorax, and its contraction rotates the pelvis toward the contralateral side relative to the thorax. Ipsilateral isometric hip internal and contralateral external rotation causes rotational moment toward the ipsilateral side on the pelvis, thus IO and TrA were activated coordinately to stabilize the trunk against that moment.

Muscle activation of EO increased in ipsilateral hip isometric external rotation and contralateral hip internal rotation during trunk stabilizing exercise. However, EO muscle thickness showed small changes among exercise conditions except for contralateral ASLR. Muscle activation and muscle thickness of EO were inconsistent with each other. Previous studies also reported that the relationship between the change in muscle thickness and increase in muscle activity is weak or inverse in the case of EO (Hodges et al., 2003; John and Beith, 2007). Because EO is the most surficial of abdominal muscles and no muscle causes crosstalk, the muscle activity measured by EMG is more reliable than muscle thickness measured by USI. The EO has an opposite function to IO in trunk rotation, thus EO muscle activation was increased by an opposite load to the hip joint during the trunk stabilizing exercise.

Muscle activation of MF increased in all hip isometric rotation

Table 1
Difference of muscle activation (%MVC) between exercise condition.

	Ipsi-HIR	Ipsi-HER	Contra-HIR	Contra-HER	AC	Ipsi-ASLR
A. IO						
Ipsi-HIR (20.8 ± 11.6)						
Ipsi-HER (8.6 ± 5.7)	12.2**					
Contra-HIR (8.1 ± 5.4)	12.7**	0.5				
Contra-HER (13.7 ± 9)	7.2**	−5.1	−5.6*			
AC (10.7 ± 5.8)	10.1*	−2.1	−2.6	3.0		
Ipsi-ASLR (9.2 ± 6.5)	11.6**	−0.6	−1.1	4.4	1.5	
Contra-ASLR (5.5 ± 4.5)	15.3**	3.1	2.6	8.1**	5.1*	3.7
B. EO						
Ipsi-HIR (4.8 ± 2.9)						
Ipsi-HER (11.6 ± 9.2)	−6.8**					
Contra-HIR (11.2 ± 9.1)	−6.4**	0.4				
Contra-HER (4.3 ± 2.8)	0.6	7.3**	6.9*			
AC (6.0 ± 3.5)	−1.2	5.6	5.2*	−1.7		
Ipsi-ASLR (4.6 ± 4.8)	0.2	7.0**	6.6**	−0.3	1.4	
Contra-ASLR (3.0 ± 2.7)	1.9	8.6**	8.3**	1.3	3.0*	1.7
C. RA						
Ipsi-HIR (2.8 ± 2.8)						
Ipsi-HER (2.5 ± 3.4)	0.3					
Contra-HIR (2.6 ± 2.9)	0.2	−0.1				
Contra-HER (2.2 ± 1.5)	0.6	0.3	0.4			
AC (17.2 ± 7.3)	−14.4**	−14.7**	−14.6**	−15.0**		
Ipsi-ASLR (2.8 ± 3.1)	−0.1	−0.3	−0.3	−0.6	14.4**	
Contra-ASLR (2.4 ± 2.1)	0.4	0.1	0.2	−0.2	14.8**	0.4
D. MF						
Ipsi-HIR (25.7 ± 13.4)						
Ipsi-HER (15.5 ± 8.0)	10.2**					
Contra-HIR (17.3 ± 10.2)	8.4**	−1.8				
Contra-HER (22.8 ± 12.5)	2.9	−7.3	−5.5			
AC (2.1 ± 1.7)	23.6**	13.4**	15.2**	20.7**		
Ipsi-ASLR (3.2 ± 2.8)	22.5**	12.3**	14.1**	19.6**	−1.1	
Contra-ASLR (3.4 ± 3.5)	22.4**	12.1**	13.9**	19.4**	−1.3	−0.2

Abbreviations: IO, internal oblique; EO, external oblique; RA, rectus abdominis; MF, multifidus; Ipsi-HIR, ipsilateral hip internal rotation; Ipsi-HER, ipsilateral hip external rotation; Contra-HIR, contralateral-hip internal rotation; Contra-HER, contralateral hip external rotation; AC, abdominal crunch; Ipsi-ASLR, ipsilateral-active straight leg raise; Contra-ASLR, contralateral-active straight leg raise. Each measured value (%MVC) is expressed as mean ± SD in parentheses.

** $p < 0.01$.

* $p < 0.05$.

conditions during trunk stabilizing exercise. Contraction of abdominal oblique muscles to counter the pelvis rotational force also causes trunk flexion. The MF balances the trunk flexion force caused by abdominal oblique muscles, and stabilizes the trunk. Thus, MF was activated in any isometric hip rotation conditions during trunk stabilizing exercise. Present trunk exercise could effectively induce co-contraction of core muscle required for trunk stabilization, and may be useful to patients with weakened trunk muscle or low back pain.

Core muscles respond predictively to counter the force caused by lower and upper extremity motion prior to the initiation of movement in daily activity (Hodges et al., 1999; Kim et al., 2016; Lee et al., 2013; Tsao and Hodges, 2007). For instance, rapid bilateral movement of the upper limb in standing position increases activity of the trunk muscle in the direction opposite to the resulting movement (Hodges et al., 1999). Moreover, external load on the unilateral extremity induces greater contraction of trunk muscle than the external load on bilateral extremities during exercise (Mullington et al., 2009). Previous studies indicated an increased contraction of trunk muscle in front bridge exercise with unilateral hip adduction load (Kim et al., 2016), and in shoulder horizontal abduction exercise using a latex resistance band in sitting position (Lee et al., 2013). These findings suggested that the external load on the unilateral extremity effectively promotes activities of the abdominal oblique muscle group in order to counter the rotation moment acting on the trunk. Thus, trunk stabilizing exercise with unilateral isometric hip rotation effectively induced the core muscle contraction in this study.

There were several limitations to this study. The results may not be generalizable to patients with LBP, because muscle activity of only healthy subjects was analyzed in this study. We did not analyze the long term effect of the exercise. Further study focusing on patients with weakened trunk muscles is necessary to clarify the effectiveness of trunk stabilizing exercise with isometric hip rotation.

5. Conclusion

We investigated core muscle activation during trunk stabilizing exercise with isometric hip rotation in the supine position. The results indicated that this exercise induced greater muscle contraction in IO, EO, TrA and MF than that observed during AC and ASLR. This trunk stabilizing exercise is safe and effective in promoting deep muscle activity of the trunk, and may be used for the prevention and treatment of low back pain.

Declaration of Competing Interest

The authors declare that they have no conflict of interest and this study was not funded.

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Table 2
Difference of muscle thickness (percentile of muscle thickness relative to the rest) between exercise condition.

	Ipsi-HIR	Ipsi-HER	Contra-HIR	Contra-HER	AC	Ipsi-ASLR
A. IO						
Ipsi-HIR (142.4 ± 16.5)						
Ipsi-HER (106.5 ± 9.9)	35.9**					
Contra-HIR (105.6 ± 14.1)	36.8**	0.9				
Contra-HER (131.4 ± 17.0)	11.0**	−24.9**	−25.7**			
AC (115.9 ± 11.6)	26.5**	−9.4	−10.3*	15.4**		
Ipsi-ASLR (106.4 ± 10.3)	36.0**	0.1	−0.8	24.9**	9.5	
Contra-ASLR (108.7 ± 9.8)	33.7**	−2.2	−3.1	22.7**	7.2	−2.3
B. EO						
Ipsi-HIR (99.3 ± 9.5)						
Ipsi-HER (102 ± 8.4)	−2.7					
Contra-HIR (103.9 ± 14.7)	−4.7	−2.0				
Contra-HER (100.8 ± 7.2)	−1.5	1.2	3.2			
AC (97.4 ± 8.5)	1.8	4.5	6.5	3.3		
Ipsi-ASLR (97.7 ± 7.0)	1.6	4.3	6.3	3.1	−0.3	
Contra-ASLR (109.1 ± 9.5)	−9.9*	−7.2	−5.2	−8.4*	−11.7**	−11.4**
C. TrA						
Ipsi-HIR (144.5 ± 27.4)						
Ipsi-HER (109.8 ± 18.29)	34.7**					
Contra-HIR (118.1 ± 30.7)	26.4**	−8.3				
Contra-HER (129.2 ± 25.7)	15.3*	−19.4*	−11.1			
AC (110.9 ± 11.9)	33.6**	−1.1	7.2	18.3*		
Ipsi-ASLR (104.6 ± 11.8)	39.9**	5.2	13.5	24.6	6.3	
Contra-ASLR (106.5 ± 12.2)	38.0**	3.3	11.6	22.7	4.4	−1.9

Abbreviations: IO, internal oblique; EO, external oblique; TrA, transverse abdominis; Ipsi-HIR, ipsilateral hip internal rotation; Ipsi-HER, ipsilateral hip external rotation; Contra-HIR, contralateral hip internal rotation; Contra-HER, contralateral hip external rotation; AC, abdominal crunch; Ipsi-ASLR, ipsilateral-active straight leg raise; Contra-ASLR, contralateral-active straight leg raise. Each measured value is expressed as mean ± SD in parentheses.

** $p < 0.01$.

* $p < 0.05$.

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