Electromyographic analysis of trunk-muscle activity during stable, unstable and unilateral bridging exercises in healthy individuals

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Abstract

Background Spinal pain can result in unilateral atrophy of spinal muscles. Understanding side-to-side muscle activity during exercises can help clinicians address these deficits. This study determined if variations of bridging exercises specifically activated side-to-side trunk-muscle activity.

Method Using surface electromyography on 20 healthy subjects (16 females), age 25.45 (± 3.57) years, height 166 (± 0.8) cm, weight 63.35 (± 12.70) kg, muscle activity of left and right lumbar multifidus, iliocostalis lumborum thoracis (ICLT), rectus abdominis (RA) and external oblique (EO) was recorded during eight bridging exercises with stable, unstable and unilateral (left-leg off the ground) conditions.

Results There were significant side-to-side differences in abdominal-muscle activity during all unstable exercises (mean difference range from 3.10 %MVC for RA to 9.86 %MVC for EO), and during all unilateral exercises (mean difference range from 3.22 %MVC for RA to 9.41 %MVC for EO), with the exception of RA in exercise-7. For the back muscles, there were significant side-to-side differences for multifidus during all unilateral exercises (mean difference range 5.35 %MVC to 11.72 %MVC), with the exception of exercise-5. None of the bilateral exercises (stable or unstable) produced side-to-side differences for multifidus. For ICLT only exercise-3 produced significant side-to-side differences with a mean difference of 5.5 %MVC. In all cases where significant

differences were noted, the left side of the muscles demonstrated the higher values.

Conclusion The results suggest that specific exercises (unilateral/unstable) can target specific sides of trunk muscles.

Keywords Electromyography · Exercises · Unilateral · Unstable · Trunk muscles

Background

Low back pain (LBP) is one of the most common and costly health problems in western societies with 5–10 % of all LBP cases becoming chronically disabled and accounting for 90 % of the cost [1]. There is a large emphasis on strengthening the trunk muscles as part of rehabilitation programmes to provide support for the spine in patients with LBP.

In patients with acute and chronic LBP, physical deconditioning of the musculature is evident and manifests as muscle atrophy, decreased muscle strength and endurance [2]. Research has shown localized and unilateral reduced cross-sectional area (CSA) of multifidus (MF) in patients with LBP at the painful level [3].

Active rehabilitation of trunk musculature has been shown to reduce LBP symptoms, increase muscle strength, CSA and endurance [4–6]. Bridging exercises are a commonly used form of training the trunk muscles and they can be applied to a large spectrum of patients with LBP [7]. It was demonstrated that incorporating unstable and unilateral conditions in these exercises led to increased muscle activation [8]. However, findings in the literature are inconsistent and the use of unstable conditions has shown higher and unchanged [7, 9] muscle activity in bridging exercises and lower [10] during unstable squats. No studies

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to date analyzed data to report any significant differences between left and right sides of the trunk muscles during bridging exercises. With regards to unilateral muscle atrophy following an episode of back pain, it is felt that this study is necessary. The aim of this study was to investigate the effects of various unstable and unilateral conditions of bridging exercises on side-to-side trunk-muscle activity using surface electromyography (sEMG), so, exercises can be prescribed appropriately. The primary hypothesis was that unstable and unilateral exercises would increase trunk-muscle activity and that unilateral exercises would increase muscle activity on the side that was unsupported (left).

Methods

Subjects

Twenty subjects (16 females), age $25.45 (\pm 3.57)$ years, height $166 (\pm 0.8)$ cm, weight 63.35 ± 12.70 kg, mean

body mass index (BMI) 23 were recruited from Cardiff University. The exclusion criteria were a history of LBP within the last 6 months, spinal surgery, lower extremity injury and/or surgery [11], pulmonary, neurological or cardiovascular conditions limiting physical activity and pregnancy. The School of Healthcare Studies, Cardiff University Ethical Research Committee approved the study and all subjects provided informed consent.

Experimental procedure

All subjects attended a single data-collection session during which they were required to complete eight different bridging exercises during stable/unstable and unilateral conditions. Prior to testing, each subject was allowed a familiarization period to ensure that they were able to perform all exercises safely and correctly. The floor was padded with gymnastic mats placed on a previously marked and standardized position. Two ball cushions (Dynair sensor 36-cm diameter, 8-cm height) were used in

Fig. 1 Trunk-muscle activity (means $\pm$ standard deviations) for all muscles for exercise-1. *LMF* left multifidus, *RMF* right multifidus, *LICLT* left iliocostalis lumborum thoracis, *RICLT* right iliocostalis

lumborum thoracis, *LEO* left external oblique, *REO* right external oblique, *LRA* left rectus abdominus, *RRA* right rectus abdominus

exercises 4 and 5. A gymnastic ball (Togu Powerball, 65-cm height was used in exercises 6, 7 and 8.

Exercises

Eight different bridging exercises were performed. The exercises, both symmetrical and asymmetrical were performed on stable and unstable surfaces [8, 12, 13] (Figs. 1, 2, 3, 4, 5, 6, 7, 8). For all subjects all unilateral exercises were performed with the left-leg lifted off the ground. In the exercises the knee was flexed at 90°, which was visually estimated.

1. Standard bilateral bridging with knees flexed at 90° and both feet resting on the ground, subjects lifted their pelvis off the ground.
2. Standard unilateral bridging with right leg on the floor at 90° knee flexion and the left-leg lifted off the ground in a fully extended position.
3. Standard unilateral bridging with both arms off the ground and vertically extended and fingertips pointing

towards the ceiling and left-leg lifted off the ground in a fully extended position.

4. Standard bilateral bridging with a ball cushion underneath each foot.
5. Standard unilateral bridging with a ball cushion under right foot and left-leg lifted off the ground in a fully extended position.
6. Ball bridging bilateral with both heels resting on a gymnastic ball.
7. Ball bridging unilateral with right heel resting on the gymnastic ball, and the left leg in a fully extended position.
8. Ball bridging bilateral with both feet on gymnastic ball and both arms extended vertically and fingertips pointing toward the ceiling.

Exercises were performed in a randomized order by drawing from an envelope. A 30 s rest period was given between each exercise [14] and the velocities of the exercises were standardized using a metronome set at a rate of 60 beats/min [7]. Subjects were given 2 s to lift their pelvis

Fig. 2 Trunk-muscle activity (means $\pm$ standard deviations) for all muscles for exercise-2. *LMF* left multifidus, *RMF* right multifidus, *LICLT* left iliocostalis lumborum thoracis, *RICLT* right iliocostalis

lumborum thoracis, *LEO* left external oblique, *REO* right external oblique, *LRA* left rectus abdominus, *RRA* right rectus abdominus. Asterisk denotes significant difference $p < 0.05$

Fig. 3 Trunk-muscle activity (means $\pm$ standard deviations) for all muscles for exercise-3. *LMF* left multifidus, *RMF* right multifidus, *LICLT* left iliocostalis lumborum thoracis, *RICLT* right iliocostalis lumborum thoracis, *LEO* left external oblique, *REO* right external oblique, *LRA* left rectus abdominus, *RRA* right rectus abdominus. Asterisk denotes significant difference $p < 0.05$

Fig. 4 Trunk-muscle activity (means $\pm$ standard deviations) for all muscles for exercise-4. *LMF* left multifidus, *RMF* right multifidus, *LICLT* left iliocostalis lumborum thoracis, *RICLT* right iliocostalis lumborum thoracis, *LEO* left external oblique, *REO* right external oblique, *LRA* left rectus abdominus, *RRA* right rectus abdominus. Asterisk denotes significant difference $p < 0.05$

Fig. 5 Trunk-muscle activity (means $\pm$ standard deviations) for all muscles for exercise-5. *LMF* left multifidus, *RMF* right multifidus, *LICLT* left iliocostalis lumborum thoracis, *RICLT* right iliocostalis lumborum thoracis, *LEO* left external oblique, *REO* right external oblique, *LRA* left rectus abdominus, *RRA* right rectus abdominus. Asterisk denotes significant difference $p < 0.05$

Fig. 6 Trunk-muscle activity (means $\pm$ standard deviations) for all muscles for exercise-6. *LMF* left multifidus, *RMF* right multifidus, *LICLT* left iliocostalis lumborum thoracis, *RICLT* right iliocostalis lumborum thoracis, *LEO* left external oblique, *REO* right external oblique, *LRA* left rectus abdominus, *RRA* right rectus abdominus. Asterisk denotes significant difference $p < 0.05$

Fig. 7 Trunk-muscle activity (means $\pm$ standard deviations) for all muscles for exercise-7. *LMF* left multifidus, *RMF* right multifidus, *LICLT* left iliocostalis lumborum thoracis, *RICLT* right iliocostalis

lumborum thoracis, *LEO* left external oblique, *REO* right external oblique, *LRA* left rectus abdominus, *RRA* right rectus abdominus. Asterisk denotes significant difference $p < 0.05$

in a steady controlled manner to the bridged position, this position had to be held for 5 s, and 2 s to lower the pelvis again in controlled way [9]. Subjects were videotaped and the video was synchronized with sEMG, so that the 5-s isometric period of the exercise that was analyzed could be flagged correctly.

Eight-channel sEMG (MyoResearch XP Clinical Application software, Noraxon Inc, Scottsdale, Arizona, USA) recorded activity of left and right RA, 3 cm lateral of the umbilicus [15], EO 15 cm lateral of the umbilicus [15] (Fig. 9), ICLT, immediately above and below the L1 level, in the middle between the midline and lateral aspect of the body [15], and MF, 2 cm lateral of the lumbosacral junction, running through the L5 spinal process [15, 16] (Fig. 10). The reference electrode was placed on the body of the sternum [17]. The skin was prepared and cleaned with alcohol wipes, with excess body-hair shaved to optimize the quality of the data collection [15]. Bipolar surface Ag/AgCl electrodes with a conductive area of 10 mm² (Kendall Meditrac 230; Tyco Healthcare, Hampshire, UK)

were attached to standardized locations on the subjects' body and in an orientation parallel to the muscle fibers and well within the borders of the muscles to avoid cross-talk [18]. The diameter of the electrodes was 18 mm, and the inter-electrode distance was 20 mm [18]. Unit specifications included input impedance $>100\text{ M}\Omega$, common mode rejection ratio $>100\text{ dB}$ and a gain of 500. EMG signals were collected at a sampling frequency of 1,000 Hz and band-pass filtered at 10–500 Hz. Data was visually inspected for heart beat artefacts. EMG linear envelopes were used for further analysis. The Linear envelopes were produced using signal smoothing by means of root mean square (RMS) (window of 100 ms).

Normalization procedures

The sEMG amplitude was normalized using three sets per muscle and a 30-s rest period between maximum voluntary isometric contractions (MVC) for each muscle [18]. Test positions were repeated as in the literature and with

Fig. 8 Trunk-muscle activity (means $\pm$ standard deviations) for all muscles for exercise-8

Fig. 9 Bipolar surface electromyographic electrode placement over the rectus abdominus and external oblique muscles

Fig. 10 Bipolar surface electromyographic electrode placement over lumbar multifidus and iliocostalis lumborum thoracis muscles

subjects on an exercise mat [16, 18]. Manual pressure was gradually increased until the maximum resistance was applied and then held for 5 s. The sEMG signal was visually checked during manual muscle tests. For RA, the MVC was performed with the subject in supine position with hips flexed 45°, knees flexed 90° and arms crossed in

front of the chest. The subject lifted the trunk to an 80°–110° flexion angle, both legs were manually fixed by the tester and resistance was applied to the crossed arms in the middle of the sternum. For right EO, the testing position was identical to the RA, but the subject additionally had to twist the trunk 45° to the left, while the tester applied

resistance to the right shoulder. The left EO was tested vice versa. The ICLT and MF were tested in the same way with a subject lying in a prone position. The tester fixed the lower extremity just above the ankle, while the subject crossed both arms behind the neck and had to lift the trunk of the ground as far as possible. After MVCs were taken the subjects were given a 2-min rest period before they performed eight different bridging exercises. Reliability of measures of sEMG activity has been reported for MF (ICC 0.88–0.87) [19], ICLT (ICC 0.84–0.71) [20], RA (ICC 0.92) [21] and for EO (ICC = 0.944) [22].

Statistical analysis

All raw sEMG data were normalized as a percentage of MVC obtained. All data are expressed as mean and $\pm$ SD. Data were analyzed using paired *t* tests to determine differences in left and right SEMG of, RA, EO, ICLT, MF activity when performing exercises 1–8. Alpha level was set at $p \leq 0.05$. All analysis was conducted using SPSS version 16.

Results

Tables 1 and 2 present the means, standard deviations (SD) and mean differences between left and right sides for all muscles for each exercise, with significant differences being noted. Means and SDs are represented graphically in Figs. 1, 2, 3, 4, 5, 6, 7 and 8. The highest sEMG values of all muscles were seen for MF (Table 1), followed by ICLT (Table 1). The abdominals showed lower values than the back muscles, with the highest values in EO (Table 2), followed by RA (Table 2). No significant differences were seen in any muscle in exercise-1 (Fig. 1). There were significant side-to-side differences in abdominal-muscle activity during all unstable exercises (Figs. 4, 5, 6, 7, 8) with the mean difference ranging from 3.1 %MVC for RA to 9.86 %MVC for EO, and during all unilateral/stable exercises (Figs. 2, 3), with the mean difference ranging from 3.22 %MVC for RA to 9.41 %MVC for EO, with the exception of RA (exercise-7, Table 2). In all cases of unilateral and unstable exercises the left side demonstrated the higher values (Table 2).

For the back muscles, there were significant side-to-side differences, for multifidus during all unilateral exercises (Figs. 2, 3, 7) (mean difference ranging between 5.35 and 11.72 %MVC), with the exception of exercise-5 (Fig. 5). In all cases, the left side demonstrated the higher values (Table 1). None of the bilateral exercises (stable or unstable) produced side-to-side differences for multifidus (Table 1). For ICLT only exercise-3 (Fig. 3) produced

significant side-to-side differences with a mean difference of 5.5 %MVC.

Discussion

Rehabilitation in the form of exercise on unstable surfaces is often prescribed for patients with LBP [8, 17]. Unilateral atrophy of MF following an episode of LBP has been reported [3]. This is one of the few studies reporting significant differences between the left and right sides separately. Previous studies have summed left and right side trunk-muscle activity together [17], or where left and right sides have been reported descriptive data only was presented with no further analysis [17] or data was only collected on one side during unilateral exercises [23].

The current study demonstrates that unilateral bridging exercises produced significant side-to-side differences in the amplitude (% MVC) in the majority of the muscles. The significant side to side difference during unilateral exercise could be explained by the requirement to counteract the force of gravity to maintain the trunk and pelvis in a bridged position. Furthermore unilateral conditions might have induced rotational forces around the trunks' longitudinal axis due to loss of support which requires increased muscle activity. In some cases, stability component as well as unilateral conditions were combined and so the increased muscle activity may have been caused by a combination of the two conditions. The most challenging exercise demonstrating the greatest side-to-side difference for both back muscles and EO is exercise-7 (unilateral unstable). For RA the most challenging exercise is exercise-8 (bilateral unstable).

The results in part support the hypotheses that unstable and unilateral conditions increase trunk-muscle activity. This is in agreement with previous work [8, 17], but contradicts other results where no difference in trunk-muscle activity in supine bridging exercises was observed [8]. Compared to other studies that investigated a large spectrum of different exercises [8], with unstable and unilateral conditions this paper focuses on one type of exercise with variations of unstable and unilateral conditions.

Previous results which suggest no differences in muscle activity on the gymnastic ball compared to the standard bridge appear to contradict our findings [7]. This may be explained by the use of a more stable position with the knees flexed to 90° in the previous study as opposed to the unsupported limbs being extended, as in the current study. Research has also shown increased muscle activity in unilateral exercises on the supported side [8] this contradicts the results from this study, however, results are not like to be comparable, because in this study, upper limb dumbbell presses were investigated. Bridging exercises are

Table 1 Ranked sEMG activity of the right and left MF and ICLT [means (standard deviations) and mean difference between left and right] during eight different bridging exercises

Exercise	LMF		RMF		Mean Difference between L and R (SD)		LICT		RICLT		Mean difference between L and R (SD)	
	Rank	Value	Rank	Value			Rank	Value	Rank	Value		
1	8	34.14 (10.84)	8	34.19 (12.3)	0.02 (7.54)	8	26.92 (7.1)	8	27.01 (8.8)	0.10 (4.30)		
2	6	45.72 (12.54)	7	40.37 (11.65)	5.35* (9.72)	6	35.15 (12.81)	7	34.18 (9.16)	1.0 (7.97)		
3	4	50.27 (16.12)	4	42.37 (13.6)	7.9* (10.27)	3	44.05 (15.35)	4	38.55 (14.93)	5.50* (11.56)		

Table 1 continued

Exercise	LMF		RMF		Mean Difference between L and R (SD)		LICT		RICT		Mean difference between L and R (SD)	
	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value
4	7	41.04 (9.15)	5	40.71 (10.57)	0.33 (10.11)	7	34.87 (8.26)	5	36.24 (13.46)	1.36 (8.56)		
5	5	46.45 (15.65)	6	40.53 (10.72)	5.91 (13.13)	4	43.94 (20.32)	6	35.96 (13.06)	7.98 (18.75)		
6	3	51.5 (14.18)	2	48.36 (16.54)	3.14 (13.12)	2	48.57 (17.49)	1	45.85 (19.75)	2.72 (14.81)		

Table 1 continued

Exercise	LMF		RMF		Mean Difference between L and R (SD)		L1CLT		R1CLT		Mean difference between L and R (SD)	
	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value
7	1	58.99 (21.78)	3	47.27 (11.07)	1	11.72* (18.86)	1	54.78 (25.51)	3	44.5 (20.22)		10.28 (28.41)

8	2	54.42 (13.64)	1	50.47 (16.00)	5	3.95 (13.77)	5	43.14 (10.74)	2	45.19 (15.41)		2.04 (11.86)

All units are normalized sEMG values as a percentage maximum voluntary contraction (MVC), * denotes significant difference

LMF left multifidus, RMF right multifidus, L1CLT left iliocostalis lumborum thoracis, R1CLT right iliocostalis lumborum thoracis, L left, R right

Table 2 Ranked sEMG activity of the right and left EO and RA [means (standard deviations), mean difference between left and right) during 8 different bridging exercises

Exercise	LEO		REO		Mean Difference between L and R (SD)		LRA		RRA		Mean difference between L and R (SD)	
	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value
1	8	12.18 (14.94)	7	10.18 (13.33)	2.00 (10.7)	8	8.6 (5.45)	8	7.03 (3.44)	1.57 (4.8)		
2	4	22.23 (16.51)	5	12.81 (9.51)	9.41* (11.17)	4	14.63 (6.7)	3	11.4 (5.61)	3.22* (5.05)		
3	5	19.94 (16.45)	4	12.94 (11.00)	7.0* (9.30)	3	14.8 (7.04)	4	10.65 (5.41)	4.15* (5.84)		

Table 2 continued

Exercise	LEO		REO		Mean Difference between L and R (SD)		LRA		RRA		Mean difference between L and R (SD)	
	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value
4	7	12.85 (14.47)	8	8.31 (9.81)	4.54* (8.19)	7	11.39 (8.48)	7	7.39 (3.4)	3.10* (8.15)		
5	2	24.1 (16.91)	1	17.31 (14.93)	6.78* (11.93)	1	17.1 (8.61)	2	13.02 (6.68)	3.99* (6.94)		
6	6	17.02 (17.12)	6	12.67 (11.63)	4.34* (7.46)	6	13.71 (8.73)	5	10.04 (5.58)	3.66 (7.9)		

Table 2 continued

Exercise	LEO		REO		Mean Difference between L and R (SD)		LRA		RRA		Mean difference between L and R (SD)	
	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value
7	1	26.4 (22.74)	2	16.54 (11.24)	2	15.88 (8.27)	1	14.44 (10.04)	1	14.44 (10.04)	1	1.34 (9.28)
8
	3	23.51 (24.28)	3	16.28 (20.27)	3	14.55 (9.09)	6	9.9 (4.17)	5	14.55 (9.09)	6	4.64* (8.63)

All units are normalized sEMG values as a percentage maximum voluntary contraction (MVC), * denotes significant difference
 LEO left external oblique, REO right external oblique, LRA left rectus abdominus, RRA right rectus abdominus, L left, R right

commonly prescribed for patients with LBP and this study provides valuable information to support treatment interventions for targeting specific trunk muscles or specific unilateral atrophy within the LBP population. Due to the large range of muscle activity shown in Tables 1 and 2, the results can be applied to patient groups where different therapeutic needs are required.

Limitations of the study include the use of sEMG, which may record muscle activity from neighbouring muscles, thus not truly representing the muscle activity of the muscle of interest. In addition, this study utilized healthy subjects, therefore the data acquired is not representative of data collected from subjects with back pain. Visual estimation of the knee flexion angle may have resulted in a variation of the knee position, which in turn may have influenced muscle-activation patterns. More accurate methods of standardization would enhance the robustness of the data. Leg dominance may have influenced the results in this study, however, the effect of this is open to conjecture as leg dominance was not recorded in this study. Moreover, no left-to-right differences were demonstrated in other literature investigating bilateral trunk-muscle activity in unilateral exercises in healthy subjects [9]. The position of the trunk changed during all the ball bridging exercises compared to exercises where the feet were on the floor and it is not clear how this influenced muscle activity. Unilateral and unstable exercises were combined which makes it difficult to determine which condition was responsible for changes in sEMG. EO activity on the left seems to be constantly increased regardless of the exercise condition and until further investigations are made these results should be viewed with caution. sEMG reliability data were taken from the previous studies and was not assessed during this study. Therefore, although the exercises were standardized, the detected differences may have reflected the inherent variability in human performance rather than a true difference between two conditions. Further research investigating the deep trunk muscles including transversus abdominus and in patients with LBP are needed.

Conclusion

Unstable and unilateral conditions generally increased muscle activity for all investigated muscles. In unilateral exercises, in most cases, where significant differences were noted, the unsupported side (left side) demonstrated the highest activity. These results provide guidance when using bridging exercises with a variety of unstable and unilateral conditions.

Conflict of interest None.

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