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original article

Trunk stabilization exercises for healthy individuals

Exercícios de estabilização do tronco para indivíduos saudáveis

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Abstract – The aim of this study was to analyze the trunk muscular response during different variations of some of the most popular stabilization exercises: front-bridge, back-bridge, side-bridge, and bird-dog. Surface electromyography was bilaterally recorded from rectus abdominis, external and internal oblique and erector spinae during 25 variations of the aforementioned exercises. Compared to the conventional form of the front- and side-bridge, performing these exercises kneeling on a bench or with elbows extended reduced the muscular challenge. Conversely, performing the back-bridge with elbows extended elicited higher muscular activation than the conventional exercise. While bridge exercises with double leg support produced the highest activation levels in those muscles that counteracted gravity, single leg support while bridging increased the activation of the trunk rotators, especially internal oblique. The highest activation levels were found in three exercises: sagittal walkout in a front-bridge position, rolling from right side-bridge into front-bridge position, and side-bridge with single leg support on a BOSU™ balance trainer. Although the exercises performed on unstable surfaces usually enhanced the muscle activation, performing the exercises on the BOSU™ balance trainer did not always increase the trunk muscle activity. Overall, this information may be useful to guide fitness instructors and clinicians when establishing stabilization exercise progressions for the trunk musculature.

Key words: Electromyography; Exercise; Postural balance.

Resumo – *O objetivo do presente estudo foi analisar a resposta muscular durante a realização de diferentes variações de alguns dos exercícios mais populares para estabilização do tronco: front bridge, back bridge, side bridge e bird-dog. Registou-se bilateralmente a electromiografia dos músculos recto abdominal, oblíquo externo, oblíquo interno e eretor da espinha durante 25 variações desses exercícios. Comparado com a forma tradicional do front bridge, o side bridge reduziu a ativação muscular na execução dos exercícios com os joelhos apoiados ou com os cotovelos estendidos. Contrariamente, a execução do back bridge com os cotovelos estendidos produziu maior ativação comparativamente com o exercício tradicional, enquanto a realização dos exercícios bridge com as duas pernas apoiadas produziu níveis mais altos de ativação dos músculos antigravitacionais. Os exercícios bridge realizados com apoio monopodal incrementaram a ativação dos rotadores do tronco, especialmente, do oblíquo interno. O maior nível de ativação encontrou-se em três exercícios: sagittal walkout na posição de front bridge, rolling desde right side bridge para front bridge, e side bridge com uma perna apoiada sobre uma superfície instável (BOSU™ balance trainer). Embora os exercícios sobre superfícies instáveis normalmente aumentem a ativação muscular, a utilização do BOSU™ balance trainer nem sempre incrementou a atividade dos músculos do tronco. Os resultados do presente estudo podem ser úteis para guiar instrutores de ginástica e terapeutas no planeamento de progressões de exercícios destinados à estabilização da musculatura do tronco.*

Palavras-chave: *Eletromiografia; Equilíbrio postural; Exercício.*

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INTRODUCTION

The concept of spine stability has become a major focus in the scientific and clinical literature. From a biomechanical point of view, spine stability has been understood as the ability of a loaded spine to maintain static equilibrium even when subjected to small fluctuations around this position[1]. Passive and active trunk structures under the control of the neural system participate in spine stabilization[2]. In this respect, several biomechanical studies have shown that the coordinated activation of the trunk musculature provides a stiffening mechanism to the spine and thus enhances stability[3-5].

Many trunk exercises have been suggested as stabilization exercises in clinical, recreational and sport settings. According to Professor Stuart McGill's research group[6,7], a stabilization exercise is any exercise that challenges the spine stability while grooving trunk co-activation patterns that ensure a stable spine. From a practical point of view, these exercises usually consist of holding the spine in a "neutral" position with minimal associated movement, while the trunk is loaded using different strategies, for example: a) moving the upper and/or lower limbs in several positions, such as quadruped (e.g.: "bird-dog") or lying positions (e.g.: "dead-bug")[8-12]; b) maintaining the pelvis lifted off the floor against gravity in supine, prone or lateral positions (e.g.: "bridging")[8,10,11,13,14]; c) using different devices such as fitball[9,14-17], BOSU™ balance trainer[14], cable pulley machines[18,19] or oscillation poles[20,21], and d) combining any of the above strategies.

In the present study, the trunk muscle electromyography (EMG) of a healthy individual was recorded and analyzed during a batch of stabilization exercises which were performed based on all the aforementioned strategies. The aim was to obtain information to help establish a progression for four of the most popular stabilization exercises: front-bridge, back-bridge, side-bridge and bird-dog.

PROCEDURES METHODS

Participant

The participant in this study was an asymptomatic 31-year-old man, with a body weight of 59.7 kg and a height of 165.1 cm. He was healthy without current back, hip or shoulder pain or past pathology in these regions. In addition, he was recreationally trained and familiar with trunk stabilization exercises. Written informed consent was obtained from this participant prior to testing. The experimental procedures used in this study were in accordance with the Declaration of Helsinki.

Trunk stabilization exercises

The participant was instructed to perform several variations of the conventional front-bridge, back-bridge, side-bridge and bird-dog exercises:

Front-bridges (Figure 1): the subject maintained the pelvis lifted off a bench in a prone position, with the trunk fully aligned with the thighs. Eight variations of this exercise were performed: with elbows extended (Figure 1a); kneeling on a bench (Figure 1b); conventional front-bridge (Figure 1c); with elevated right leg (Figure 1d); with feet resting on the BOSU™ balance trainer (Figure 1e); with left foot resting on the BOSU™ balance trainer and elevated right leg (Figure 1f); starting from the front-bridge position on the wall, with elbows extended, walkout moving the hands up 30 cm (Figure 1g); starting from the front-bridge position on the bench, with elbows extended, walkout moving the hands forward 30 cm (Figure 1h).

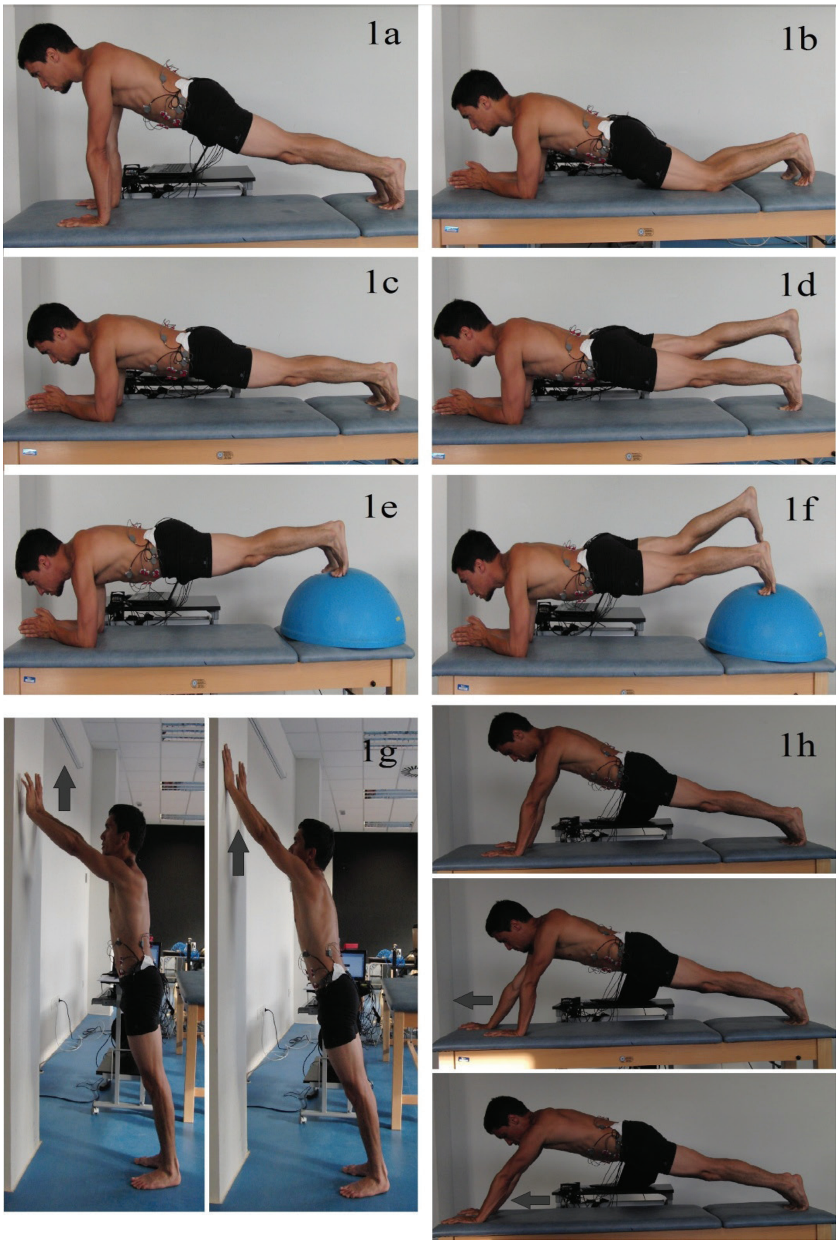

Figure 1. Images of the subject performing different forms of the front-bridge exercise: 1a) elbows extended; 1b) kneeling on the bench; 1c) conventional front-bridge; 1d) elevated right leg; 1e) feet resting on the BOSU™ balance trainer; 1f) left foot on the BOSU™ balance trainer and elevated right leg; 1g) sagittal walkout on the wall; 1h) sagittal walkout on the bench.

Back-bridges (Figure 2): the subject held the pelvis lifted off the bench in a supine position, with the knees bent and the trunk aligned with the thighs. Five variations of this exercise were performed: with elbows extended (Figure 2a), conventional back-bridge (Figure 2b), with elevated right leg (Figure 2c), with feet resting on BOSU™ balance trainer (Figure 2d), with left foot resting on the BOSU™ balance trainer and elevated right leg (Figure 2e).

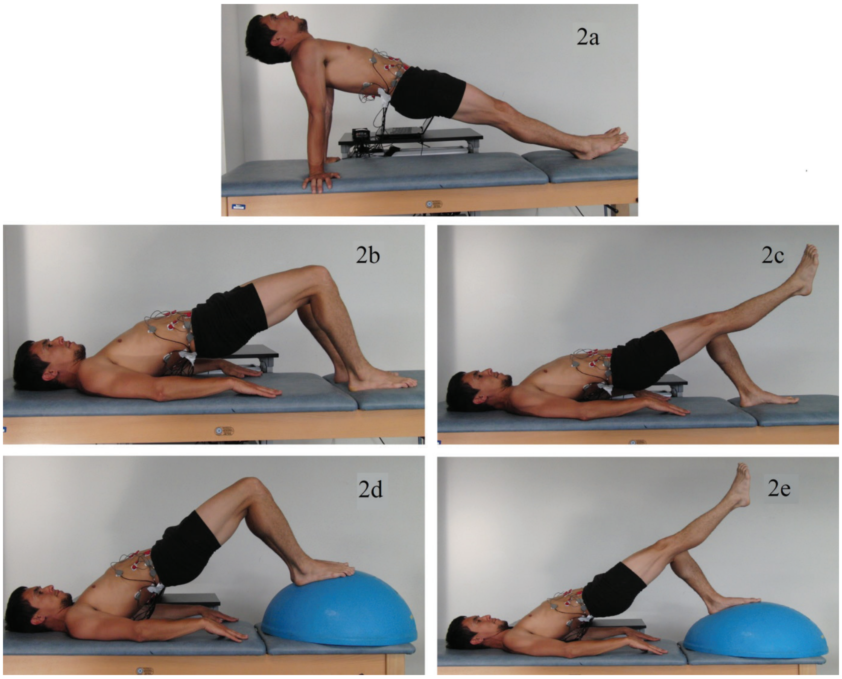

Figure 2. Images of the subject performing different forms of the back-bridge exercise: 2a) elbows extended; 2b) conventional back-bridge; 2c) elevated right leg; 2d) feet resting on the BOSU™ balance trainer; 2e) left foot on BOSU™ balance trainer and elevated right leg.

Right side-bridges (Figure 3): the subject maintained the pelvis lifted off the bench in a right lateral position, with the trunk fully aligned with the thighs. Eight variations of this exercise were performed: with right elbow extended (Figure 3a), resting on the right elbow and knee (Figure 3b), conventional right side-bridge (Figure 3c), with left hip flexion (Figure 3d), with feet resting on BOSU™ balance trainer (Figure 3e), with right foot resting on the BOSU™ balance trainer and left hip flexion (Figure 3f), rolling on the wall from the right side-bridge into the front-bridge position (Figure 3g), rolling on the bench from the right side-bridge into the front-bridge position (Figure 3h).

Bird-dogs (Figure 4): the subject maintained a 2-point kneeling position, with a contralateral arm and leg raise. Four variations of this exercise were performed: with elevated right arm and left leg (Figure 4a); with elevated right arm and left leg while drawing circles in the air with the raised limbs (Figure 4b); with elevated right arm and left leg on the BOSU™ balance trainer (Figure 4c); with elevated right arm and left leg on the BOSU™ balance trainer while drawing circles in the air with the raised limbs (Figure 4d).

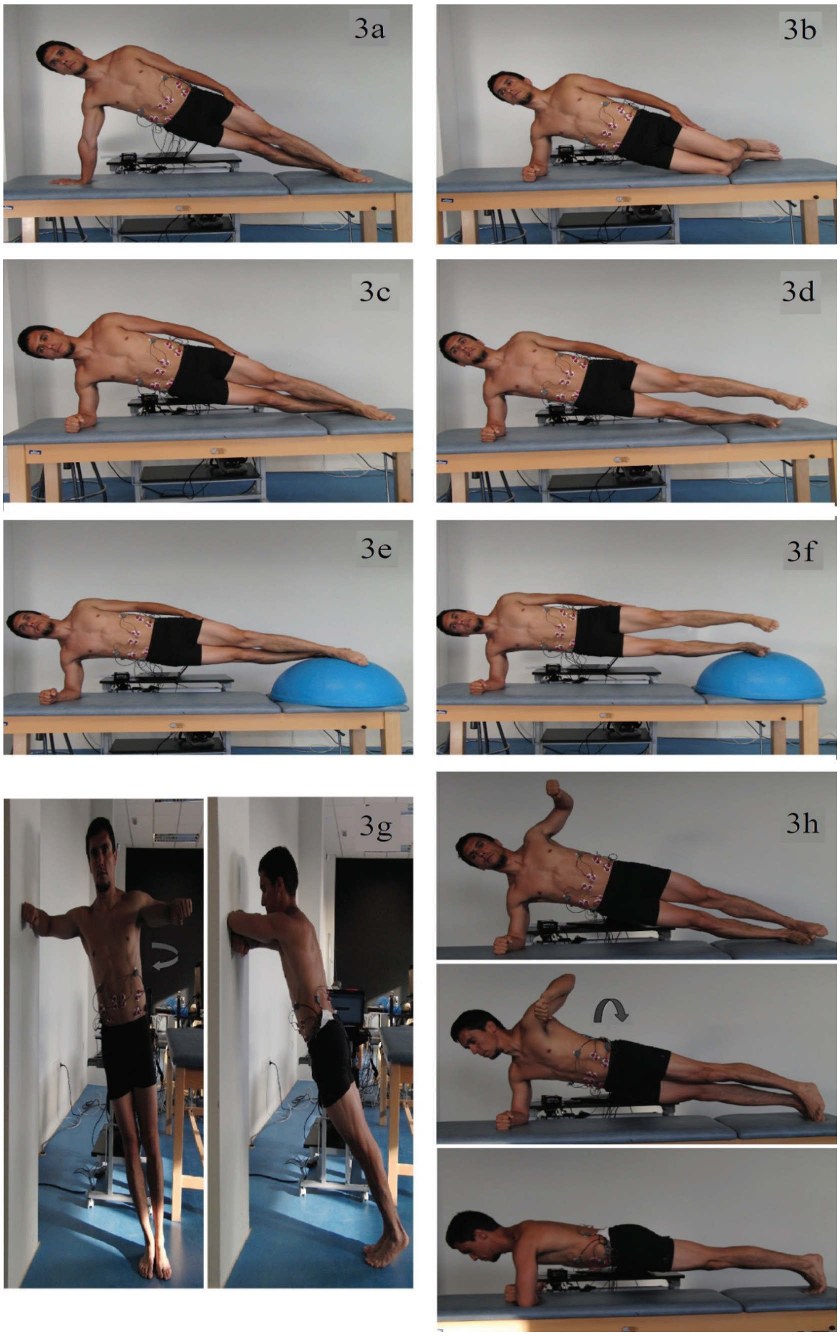

Figure 3. Images of the subject performing different forms of the right side-bridge exercise: 3a) right elbow extended; 3b) right knee on the bench; 3c) conventional right side-bridge; 3d) elevated left leg with hip flexion; 3e) feet resting on BOSU™ balance trainer; 3f) right foot on the BOSU™ balance trainer and left hip flexion; 3g) rolling on the wall; 3h) rolling on the bench.

Before data collection, the participant was instructed by the researchers to minimize trunk motion and to maintain the spine in a neutral position while performing the exercises. In particular, corrections were made by the researchers to cue the participant to avoid twisting between thorax and pelvis during some exercises[11].

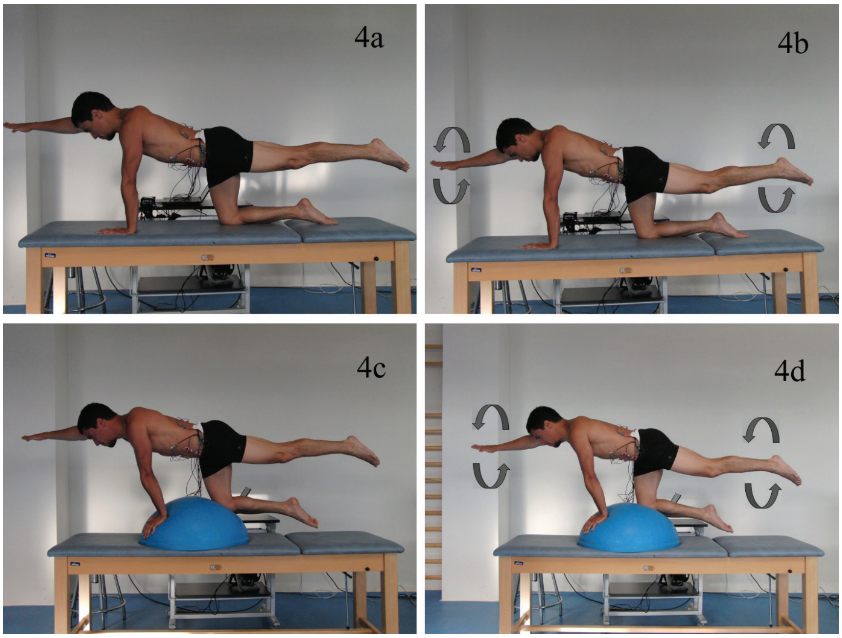

Figure 4. Images of the subject performing different forms of the bird-dog exercise: 4a) elevated right arm and left leg; 4b) elevated right arm and left leg while drawing circles with the raised limbs; 4c) elevated right arm and left leg on the BOSU™ balance trainer; 4d) elevated right arm and left leg on the BOSU™ balance trainer while drawing circles with the raised limbs.

Data collection

Surface EMG signals were collected bilaterally (R = right, L = left) from the following trunk muscles and locations: rectus abdominis (RA), approximately 3 cm lateral to the umbilicus; external oblique (EO), approximately 15 cm lateral to the umbilicus; internal oblique (IO), in the geometric center of the triangle formed by the inguinal ligament, the outer edge of the rectus sheath and the imaginary line between the anterior superior iliac spine and the umbilicus; and erector spinae (ES), 3 cm lateral to L3 spinous process. The Muscle Tester ME6000® (Mega Electronics Ltd., Finland) was used for the EMG recordings. This is a portable microcomputer with an 8-channel A/D conversion (14 bit resolution), a CMRR of 110 dB and a band-pass filter of 8-500 Hz. Sampling frequency was programmed at 1000 Hz. The EMG signals were transferred with an optical cable to a compatible laptop where they were monitored by the Megawin® 2.5 program (Mega Electronics Ltd., Finland).

Before data collection, pre-gelled disposable bipolar Ag-AgCl disc surface electrodes were placed in bipolar configuration on the aforementioned sites, previously cleaned with alcohol. The center-to-center electrode distance was 3 cm. Care was taken to ensure precise electrode placement to guarantee reproducibility of the measure. The subject was asked to contract his muscles to check the detection of an appropriate signal.

During the EMG recording, the participant performed a single repetition of each exercise with 5 s duration and a 1 min rest between exercises. Prior to the stabilization exercises, maximal voluntary isometric contractions (MVCs) were carried out to obtain reference values to normalize the

EMG signals. The MVC protocol has been described elsewhere in detail[22].

Data reduction

In order to remove possible artifacts, the raw EMG signals were visually reviewed. Then they were full wave rectified, averaged every 0.1 s and normalized to maximum EMG values obtained during the MVCs. In order to rank the exercises by level of muscular activation, the center 3 s window of the normalized EMG signal was averaged for each exercise and muscle.

RESULTS

Table 1 shows the mean activation level of the recorded trunk muscles during different variations of the conventional front-bridge, back-bridge, side-bridge and bird-dog exercises.

The mean levels of trunk muscle activation were low to moderate. RA was mainly activated during the front-bridge and side-bridge variations, with maximum RA activity occurring in the sagittal walkout on the bench (RRA: 43.94% MVC; LRA: 49.75% MVC). For EO, the higher levels of muscular activation were recorded during the side-bridge variations, especially when performing the rolling on the bench into the front-bridge position (right EO: 26.49% MVC). Similarly, the higher levels of IO activation were found during the side-bridge variations: 55.90% MVC for RIO in the right side-bridge on the BOSU™ balance trainer with left hip flexion, and 35,52% MVC for LIO in the rolling on the bench into the front-bridge position. The obliques were also activated during the different forms of the front-bridge, mainly when they were required to prevent twisting trunk motion in asymmetric postures or limb motions. Finally, ES was activated during the back-bridge, the side-bridge and the bird-dog variations. In particular, the right side-bridge on the BOSU™ balance trainer with left hip flexion and the back-bridge with elbows extended produced the maximum activation level for RES (39.45% MVC) and LES (21.68% MVC), respectively.

The conventional front-bridge mainly activated the RA, followed by the obliques. The activation of the abdominal muscles was reduced when the front-bridge was performed kneeling on the bench or with elbows extended. Similarly, the RA and EO normalized EMG was very low during the sagittal walkout on the wall (e.g.: RRA: 3.03% MVC; REO: 2.34% MVC). When the front-bridge exercises were carried out with the right leg elevated, the LIO activation increased and the RA activation decreased. The sagittal walkout on the bench was the only front-bridge variation that increased the activation of all abdominal muscles. Interestingly, performing the front-bridges on the BOSU™ balance trainer did not produce any effect on the trunk muscle EMG.

The conventional back-bridge isolated the activation of the ES. The activation of this muscle increased when the back-bridge was performed with elbows extended or with feet resting on the BOSU™ balance trainer. In addition, the back-bridge variations with right leg elevated increase the RIO activity.

Table 1. Mean normalized surface electromyography amplitudes (% MVC) for each muscle tested during different variations of the conventional front-bridge, back-bridge, side-bridge and bird-dog exercises

Exercises	Mean normalized surface electromyography amplitudes							
	RRA	REO	RIO	RES	LRA	LEO	LIO	LES
Front-bridge variations								
Conventional front-bridge	20.45	9.73	3.44	1.56	16.58	4.75	5.57	1.09
Elbows extended	12.88	8.11	2.63	1.56	11.06	4.11	2.65	1.09
Kneeling on the bench	7.20	6.31	1.60	1.17	8.04	2.93	2.79	0.91
Elevated right leg	8.71	9.91	1.60	2.54	10.55	2.93	9.75	1.46
Feet resting on BOSU™	19.32	10.45	3.55	1.56	18.09	6.40	5.85	1.09
Left foot on BOSU™ and elevated right leg	11.74	9.91	2.06	2.34	10.55	4.84	11.14	1.46
Sagittal walkout on the wall	3.03	2.34	8.25	0.98	6.53	1.65	3.34	0.73
Sagittal walkout on the bench	43.94	15.32	9.39	1.95	49.75	9.51	11.98	1.82
Back-bridge variations								
Conventional back-bridge	1.14	0.54	0.34	11.72	1.51	0.27	0.42	11.29
Elbows extended	1.89	2.16	6.76	21.29	2.01	0.46	1.39	21.68
Elevated right leg	1.89	3.06	14.32	12.30	2.01	0.64	2.51	10.93
Feet resting on BOSU™	1.52	0.90	0.92	15.04	2.01	0.37	1.25	16.39
Left foot on BOSU™ and elevated right leg	2.27	3.24	15.92	16.02	2.01	0.55	3.06	12.57
Right side-bridge variations								
Conventional right side-bridge	15.15	24.14	36.54	22.46	5.53	0.82	2.23	2.19
Right elbow extended	13.64	16.58	38.37	23.44	4.52	0.73	1.67	1.82
Right knee on the bench	6.06	11.17	10.54	15.23	2.51	0.46	2.79	1.28
Elevated left leg with hip flexion	18.56	20.90	33.56	24.41	7.04	1.01	2.09	2.37
Feet resting on BOSU™	21.21	24.14	35.62	23.63	6.53	0.91	5.85	2.00
Right foot on BOSU™ and left hip flexion	19.70	27.03	55.90	39.45	7.54	2.74	3.20	3.10
Rolling on the wall into front-bridge	8.71	4.14	6.19	4.30	28.14	1.74	5.29	1.28
Rolling on the bench into front-bridge	29.92	26.49	23.60	8.01	21.61	8.04	35.52	4.19
Bird-dog variations								
Elevated right arm and left leg	2.65	12.25	5.15	7.62	2.51	7.40	4.32	19.31
Drawing circles with the raised limbs	2.27	8.47	5.27	5.27	2.51	4.11	3.06	12.02
Elevated right arm and left leg on BOSU™	2.65	8.83	5.84	15.23	2.51	3.02	2.09	11.66
Drawing circles with the limbs on BOSU™	2.65	10.99	7.45	21.48	3.02	4.11	2.79	15.30

RA: rectus abdominis; EO: external oblique; IO: internal oblique; ES: erector spinae; R: right; L: left.

The conventional right side-bridge activated the right side trunk muscles. The activation of these muscles was reduced when the right side-bridge was performed kneeling on the bench or when rolling on the wall into the front-bridge. In addition, the exercise with right elbow extended reduced the REO activation. In contrast, the rest of the side-bridge forms increased trunk muscle activity, especially the side-bridge with right foot on the BOSU™ balance trainer and left hip flexion, and the rolling on the bench into the front-bridge. Interestingly, in the latter exercise, which involves an important rotational torque, the REO and LIO were co-activated to prevent twisting.

The bird-dog variations mainly activated the ES, followed by the obliques. Drawing circles with the raised limbs and performing these exercises on the

BOSU™ balance trainer did not have a clear effect on the trunk muscular recruitment. It seems that the activation migrated from LES to RES.

DISCUSSION

Conventional bridge and bird-dog exercises challenge the trunk musculature while applying relatively small loads to the lumbar spine[6,23]. In the same way as observed in the present study, many EMG studies have shown that back-bridges mainly activate the trunk extensor muscles[8,10,13,14,16], front-bridges the sagittal flexor muscles[10,11,13-15], side-bridges the lateral bend muscles[10,11,13-15], and bird-dogs the trunk extensor and rotator muscles[6,10-12]. In this study, several forms of these exercises were analyzed in order to guide fitness instructors and clinicians when prescribing stabilization exercises: starting level, progression, dosage, etc.

Bridge exercises kneeling on the bench

Compared with the conventional forms, performing the front- and side-bridges kneeling on the bench reduced the weight lifted off the bench and its lever arm, and therefore the muscular challenge (Table 1). These "short" bridges seem to be a good option for beginners or for people who are concerned with safety, as they impose minimal compressive penalty on the spine[24].

Bridge exercises with elbows extended

Similarly, when the front- and side-bridges were performed with elbows extended, the lever arm of the weight lifted off the bench was shorter than during the conventional forms, and consequently the muscular activation levels were lower (Table 1). This reduction in muscular activation was smaller for the side-bridge with elbows extended, maybe because the muscles were recruited in some way to ensure body balance (since during this side-bridge variation the height of the center of gravity was higher and the base of support smaller). Regarding the back-bridge variations, the weight lifted off the bench and its lever arm were higher during the exercise with elbows extended. Therefore, unlike the front- and side-bridges, the back-bridge with elbows extended produce higher muscular activation levels than the conventional form (Table 1). We have reviewed the literature in order to compare these results with previous data; however, despite our best efforts, we did not find studies that analyzed the effect of modifying the elbow position during bridge exercises on trunk muscular recruitment.

Bridge exercises with single leg support (an elevated leg)

The results of the present study confirm those obtained recently by our research group[10]. While bridge exercises with double leg support produced the highest activation levels in those muscles that counteracted gravity, single leg support while bridging increased the activation of the trunk rotators, especially IO. For example, compared to the conventional front- and back-bridges, performing these exercises with elevated right leg increased the activation of LIO and RIO, respectively (Table 1). The increase of the IO activation was needed to combat the rotational torque and the more unstable position caused by the unilateral leg support. Although holding asymmetric postures while bridging elicits a major muscular challenge[6,8,10,13,16], it also increases the load on the spine[6].

Stabilization exercises with limb/shoulder motion

Before moving the limbs in different positions, trunk muscle co-activation is needed to control spine stability[25]. Unilateral limb motions while performing a stabilization exercise challenge the motor system in order to stabilize the trunk and to control body balance. In this way, as determined by McGill and Karpowicz[11], drawing squares in the air with the elevated limbs during a conventional bird-dog exercise increases the activation of different muscles. However, a reduction in muscular activation was observed in our study when drawing circles in the air during the bird-dog (Table 1). It was the first time the participant performed this exercise and he was not able to hold the posture with minimal associated movement. Possibly, he paid more attention to moving the arm and leg simultaneously than to controlling the trunk posture and the neutral spine position.

The sagittal walkout can be classified as a front-bridge exercise with limb motion. The walkout on the bench elicited higher muscular activation levels than walkout on the wall (Table 1), since the lever arm of the weight supported during the former exercise was higher, data which support the results obtained by McGill et al.[18]. Similarly, rolling on the bench from the right side-bridge into the front-bridge produced higher activation levels than rolling on the wall (Table 1). Rolling and walkout on the bench generated the highest activation levels for most muscles. These exercises are not for beginners, as it is difficult to control the rotational torque applied to the trunk when the shoulder moves. In this respect, when rolling on the bench from the right side-bridge into the front-bridge position, REO and LIO were co-activated (Table 1) to produce rotational torque and to prevent twisting between thorax and pelvis. This oblique co-activation on opposite trunk sides to generate twisting torque was also observed in previous studies[10,26,27].

Stabilization exercises on the BOSU™ balance trainer

Labile surfaces (e.g.: BOSU™ balance trainer or fitball) are frequently used during trunk exercises to challenge spine stability. As compared to exercises on stable surfaces, many studies have demonstrated that exercises performed on unstable surfaces usually enhanced trunk muscle activation[14,17]. However, as shown in Table 1, the addition of an unstable surface to trunk exercises does not always have an effect on the muscular response[9,14,15], and may even reduce the muscular challenge[9]. Possibly, the effect of these devices depends on both the way they are used and the individual's fitness level.

Limitations of the study

In order to establish safe trunk stabilization exercise progressions, further biomechanical studies should assess both muscular recruitment and spine loading. In addition, interpretation of the results of this study is limited because our subject was relatively young, healthy and physically fit. In order to provide a major insight on trunk muscle response during stabilization exercises, future studies should analyze the trunk muscular recruitment of older and unfit people, and/or of patients with different spinal conditions.

CONCLUSION

The EMG data reported in this study may be used to support decision-making when prescribing trunk stabilization exercise progressions. In this respect, the following key points should be taken into consideration: i) conventional front-, back- and side-bridges mainly activate the trunk flexor, extensor and lateral bend muscles, respectively; ii) performing front- and side-bridges with elbows extended, and especially kneeling on the bench, reduces muscle activation; iii) performing back-bridges with elbows extended increases muscle activation; iv) single leg support and/or limb motions while performing stabilization exercises increase the activation of the trunk rotators, especially the internal oblique; v) performing stabilization exercises on unstable surfaces can increase the muscular challenge, but this depends on the way these devices are used.

Acknowledgments

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