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Amplitude of Electromyographic Activity of Trunk and Lower Extremity Muscles during Oscillatory Forces of Flexi-Bar on Stable and Unstable Surfaces in People with Nonspecific Low Back Pain

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ABSTRACT

Background: Recently, the oscillatory bar has been proposed as a new and effective rehabilitation tool in people with nonspecific low back pain (NSLBP), although its effects on muscular control in this population have not been well documented, especially in lower extremity muscles and different support surface conditions.

Objective: This study aimed to evaluate and compare the effects of flexi-bar use on stable and unstable surfaces on electromyographic activity of trunk and lower extremity muscles in healthy persons and those with NSLBP.

Material and Methods: 18 healthy men and 18 men with NSLBP participated in this cross-sectional study. The root mean square value of electromyographic activity was calculated in the trunk and lower extremity muscles during 4 different task conditions: quiet standing (QS) or flexi-bar use on a rigid or foam support surface. A repeated measures test was used for statistical analysis.

Results: The results showed that the amplitude activity of almost all muscles was significantly greater during flexi-bar use than in the QS condition (P<0.05). The rectus femoris, tibialis anterior, and gastrocnemius demands were significantly greater on the foam than the rigid surface (P<0.05).

Conclusion: This study showed that oscillatory forces caused by flexi-bar use can increase muscle activation in multiple segments (hip and ankle in addition to trunk muscles) that are crucial for postural stability. Furthermore, the foam surface appeared to target the rectus femoris in addition to the ankle muscles. Using a flexi-bar may be helpful in NSLBP rehabilitation, and exercising on a foam surface may enhance additive hip muscle activity in people with NSLBP.

Keywords

Electromyography; Muscles; Lower Extremity; Low Back Pain; Task Performance and Analysis; Oscillatory Device; Rehabilitation

Introduction

Nonspecific low back pain (NSLBP), characterized by a lack of a specific etiology, accounts for 85% of low back complaints [1, 2]. Despite efforts to understand and manage this worldwide health problem recurrences are common and have high economic costs

[1]. Therefore, it remains a crucial objective to study this population to improve LBP rehabilitation protocols. Appropriate global trunk and local muscle activation is essential for spinal stability during different daily activities such as quiet stance and movements, including those made in response to mechanical perturbations [3]. Increasing evidence that shows muscular alteration in people with LBP (e.g. amplitude, timing, and recruitment patterns) [4-6] creates an urgent need to develop new exercise tools targeted at muscular recruitment and spinal stability disorders. Therefore, there have been efforts to introduce exercises in a "task-specific" manner, matched to daily and occupational activities [7] such as using vibrating tools or traveling in different types of vehicles.

Recently, the flexi-bar has been proposed as an effective, portable, and inexpensive tool in LBP rehabilitation. It has been increasingly used to train strength, endurance, coordination, balance, proprioception, and joint stability [8, 9], although its effects have not been well documented. Flexi-bar exercises involve oscillation of the bar by active elbow movements that need a stabilized trunk foundation for upper extremity movements [10]. This tool automatically triggers activity in local (multifidus, transverse abdominis, and internal oblique) and global core muscles (rectus abdominis and erector spine) to control the trunk against oscillatory forces created by the flexi-bar [11, 12]. Recent studies have investigated factors that should be considered to guide clinicians' prescription practices, e.g. different postures (standing, sitting, quadruped, and post pelvic tilt) and bar orientation (vertical or horizontal) in healthy people [10-13]. They suggested that posture and bar orientation can determine the muscles that are targeted in training with a flexi-bar. However, how motor control regulates this task on a rigid and foam surface remains poorly understood. According to earlier work, the central nervous system regulates muscular control at a more proximal level and increases the activity level on an unstable support surface [14-16]. Therefore, the mechanisms that control responses to perturbations may differ when the flexi-bar is used on different surfaces. Also, to the best of our knowledge, previous studies have investigated muscle responses mostly at the trunk level during flexi-bar use. However, LBP may contribute to altered strategies at distal or proximal sites in the low back. Therefore, evaluating lower extremity muscle activity alongside trunk activity may be helpful to gain better insights into the effects of the flexi-bar. Only a few studies showed pain, disability, and transverse abdominis thickness improvements after flexi-bar exercise programs in people with LBP [17, 18]. However, there are no published studies evaluating trunk and lower extremity EMG activity in individuals with LBP during flexi-bar use. Such studies may provide information to better explain the biomechanical mechanisms of clinical improvements after flexi-bar use in this population. Also, detailed studies of muscle activation during flexi-bar use can help clinicians to choose the optimal exercise conditions for specific LBP impairments. Whether trunk and lower extremity muscle responses differ between healthy people and those with LBP, or whether the type of support surface modulates muscular control during flexi-bar use, have not been determined. Accordingly, this study aimed to evaluate and compare trunk and lower extremity muscle activities during flexi-bar use on a soft and rigid support surface in a sample of healthy people and people with LBP. We hypothesized that EMG activity of the trunk and lower extremity muscles would be modulated by flexi-bar use in ways that differed between the two groups and between the soft and rigid surfaces.

Material and Methods

Participants

Eighteen healthy men and 18 men with NSLBP participated in this cross-sectional study. Healthy right-handed volunteers with no history of LBP were recruited by announcements. Volunteers with a diagnosis of NSLBP were referred by physicians from local university hospitals. The inclusion and exclusion criteria of the participants are shown in Table 1. This study was approved by the local Ethics Committee of Shiraz University Medical Sciences under file number 14399.

Procedure

All participants were seen on two days at the local biomechanics laboratory. On the first day, if all inclusion and exclusion criteria were met, they were given an explanation of the protocols and written informed consent was obtained from all participants. The demographic characteristics and pain intensity in the recurrence period of LBP according to a visual analogscale (VAS) were recorded (Table 2). All participants practiced the flexi-bar exercise until they were able to perform it correctly and efficiently with active rhythmic movements of their elbows and minimum movements of their trunk and upper arm. The rhythm was controlled by a metronome set at 5 Hz (300 bpm).

Table 1: Inclusion and exclusion criteria.

Inclusion criteria (LBP):	Exclusion criteria (LBP/Healthy):
Right handed dominance	Spinal or lower extremity surgeries
At least 6 months of NSLBP (pain without any specific pathology) and three period recurrences	Spinal and lower extremity deformities
Pain intensity <3 on visual analogue scale on the test day	Orthopedic or musculoskeletal disorders of upper and lower extremities
Pain intensity of 3-7 on visual analogue scale in the LBP recurrence period	Uncorrected vision problem
Score higher than 6 on Oswestry Disability Index	Neurological, vestibular disorders and respiratory and cardiovascular diseases

On the second day, their scores on the Persian Oswestry Disability Index (ODI) [19] and Fear Avoidance Beliefs Questionnaire (FABQ) [20] were recorded, and pain value on a VAS on the test day was obtained. A 5-min warm-up and cool-down were performed before and after the start and end of the procedure. The order of the 4 conditions based on tasks (quiet standing [QS] or flexi-bar) and the type of support surface (rigid or foam) was varied randomly (Table 3).

Trunk and right lower extremity muscle EMG activity and elbow and lumbar angle values were measured in all trials for 30 s with 2 synched DataLINK Biometrics Ltd DLK900 units (Biometrics Co, UK) and software version 8.60. The data were recorded with a sampling rate of 1000 Hz (13-bit resolution) and an amplification gain of 1000, a common-mode rejection ratio of 96 dB, and a bandwidth 20–450 Hz. Thirteen bipolar paired electrodes (Biometrics surface EMG SX230, 1-cm diameter Ag/Ag-Cl and 2-cm center-to-center distance electrodes) were attached for the left and right internal oblique (LIO, RIO), external oblique (LEO, REO), thoracic erector spinae (LTES, RTES), lumbar erector spinae (LLES, RLES), right rectus abdominus (RRA), rectus femoris (RRF), biceps femoris (RBF), tibialis anterior (RTA) and gastrocnemius (RGast) muscles with double-sided adhesive tape [11, 12, 21] (Table 4). Also, two ground references (Biometrics R506) were firmly attached to the ulnar styloid processes with wrist bands. Two goniometers (Biometrics SG150 and SG150B) were used for the right elbow joint and lumbar region to control elbow and lumbar movements during the flexi-bar exercises. In this way we tried to ensure correct, consistent performance in both groups.

To minimize skin resistance, the areas were shaved and cleaned. Before the experiment, 3 repetitions of 7 s maximum voluntary contraction (MVC) were performed to normalize EMG activity of each muscle based on previ-

Table 2: Comparison of participant characteristics and angular lumbar and elbow joint movement between groups

Characteristics	Healthy Group mean±SD	NSLBP Group mean±SD	P-values
mean±SD	24.8±4.4	26.9±4.5	0.16
mean±SD	172.0± 5.3	172.7± 6.3	0.73
Age (year)	73.0± 5.4	72.1± 9.6	0.69
Height (cm)	24.7±1.2	24.1±2.6	0.40
Weight (kg)	0	17.3±5.1	NA
BMI (kg/cm^2)	0	39.2±10.9	NA
ODI (0-100)	0	15.1±3.0	NA
FABQ (0-96)	0	17.1±7.9	NA
FABQPA (0-24)	0	6.04±1.45	NA
FABQPW (0-42)	0	2.24±1.09	NA
Pain in recurrence period	30.51±17.11	27.88±12.4	0.44
Pain on test day	-1.4± 5.1	-0.9± 3.3	0.66
Elbow angle (degrees)	30.51±17.11	27.88±12.4	0.44
Lumbar angle (degrees)	-1.4± 5.1	-0.9± 3.3	0.66

BMI: body mass index, ODI: Oswestry Disability Index, FABQ: Fear Avoidance Beliefs Questionnaire, FABQPA: Fear Avoidance Beliefs Questionnaire physical activity; FABQPW: Fear Avoidance Beliefs Questionnaire physical work; NA: not applicable

Table 3: The experimental trials

Number of tests	Task	Support surface
1	QS	Rigid
2	QS	Foam
3	Flexi-bar	Rigid
4	Flexi-bar	Foam

QS: quiet stance

ous studies [10, 12] (Table 4).

During the tests, participants stood with their legs separated by their hip width, and wore an eye mask. Vision occlusion was used to increase the proprioceptive challenges in postural control [22, 23]. In QS trials, as a control position, the participants remained still. In flexi-bar trials, a flexi-bar (Liveup, Nantong, China) 621.4 g in weight, 160 cm long, and with a gripping area in the center, was used at 5 Hz natural frequency of oscillation. All participants oscillated the flexi-bar by holding the center grip with a 2-hand symmetrical hold in vertical alignment, and sagittal plane oscillation. Each test was performed 3 times. A 2-min rest was allowed between each test.

Data processing

Raw data were processed in Matlab software (Matlab R2015b, USA). A second-order Butterworth bandpass filter at 20–450 Hz and a 50 Hz notch filter were used. Then the root mean square (RMS) values of EMG data were calculated over a 200-ms moving window. The average of the three repetitions of the MVC tests was calculated for each muscle. Finally,

Table 4: Electrode placements and maximum voluntary contraction (MVC) test positions

Muscles	Electrode attachments	MVC tests positions
Right and left external oblique	15 cm lateral to the umbilicus	Abdominal muscle MVC was tested in supine and side-lying positions while performing isometric trunk flex, rotation and lateral flex.
Right and left rectus abdominis	1 cm above the umbilicus and 2 cm lateral to midline	Abdominal muscle MVC was tested in supine and side-lying positions while performing isometric trunk flex, rotation and lateral flex.
Right and left internal oblique	2 cm medial and 2 cm inferior to anterior superior iliac spine	Abdominal muscle MVC was tested in supine and side-lying positions while performing isometric trunk flex, rotation and lateral flex.
Right and left thoracic erector spine (T9)	5 cm lateral to T9 spinous process	Isometric trunk ext in Sorenson test position.
Right and left lumbar erector spine (L3)	3 cm lateral to L9 spinous process	Isometric trunk ext in Sorenson test position.
Right rectus femoris	Halfway between the anterior superior iliac spine and the superior part of the patella	Knee ext was performed in sitting position with the leg fixed at 90 degrees knee flex.
Right biceps femoris (long head)	Halfway between the ischial tuberosity and the lateral epicondyle of the tibia	Isometric knee flex was performed in prone position with the leg fixed at 70 degrees knee flex.
Right tibialis anterior	One-third of the way between the tip of the fibula and the tip of the medial malleolus	Isometric ankle dorsi-flex was performed in supine position with the ankle fixed in neutral position.
Right gastrocnemius (lateral head)	On the contracted muscle belly	Isometric ankle plantar flex was performed in prone position with the ankle fixed in neutral position.

Flex: flexion, ext: extension

the EMG activity of all muscles was normalized as the percent of MVC. The mean angle values for the elbow joint and lumbar region were obtained with goniometers.

Statistical analysis

Statistical analyses were performed with SPSS v. 21 at a significance level of P<0.05. The Kolmogorov–Smirnov test was used to verify the normality of all data. Demographic characteristics and mean elbow and lumbar angle values were compared between groups with the Mann–Whitney or independent t-test. A repeated measures analysis (group: healthy vs. LBP as the between-group variable, task: QS vs. flexi-bar and surface: rigid vs. foam as within-group variables) was used to compare %MVC of the trunk and lower extremity muscle activity between groups and conditions. Bonferroni correction was used for all significant interaction results.

Results

There was no statistically significant difference in demographic characteristics between groups (Table 2). No statistically significant difference was found between groups in lumbar and elbow joint angular movements (Table 2). This indicated that both groups performed the exercises similarly.

The results showed significant main effects for tasks in all muscles except RRF (Table 5).

Table 5: The results of (2×4) repeated measure tests to compare %MVC muscle activity between groups and conditions

	F-ratio /P-value	Group	Task	Surface	Group × surface	Group × task	Task × surface	Group × task × surface
REO	F	0.19	19.43	2.86	0.24	1.66	0.19	0.60
	P	1.75	<0.0001*	0.10	0.62	0.20	0.66	0.44
LEO	F	0.96	10.15	1.37	0.62	1.28	0.17	0.40
	P	0.33	0.003*	0.24	0.43	0.26	0.67	0.52
RRA	F	1.45	4.30	2.05	0.83	0.06	0.18	0.50
	P	0.23	0.04*	0.16	0.37	0.80	0.66	0.48
RIO	F	0.56	33.60	0.01	0.07	0.06	0.28	0.005
	P	0.45	<0.0001*	0.90	0.79	0.80	0.59	0.94
LIO	F	0.03	36.83	0.60	0.53	0.02	1.33	1.69
	P	0.85	<0.0001*	0.44	0.47	0.88	0.25	0.20
RTES	F	0.03	148.02	1.07	0.01	0.05	0.02	0.17
	P	0.87	<0.0001*	0.30	0.89	0.81	0.90	0.68
LTES	F	0.01	203.95	0.001	1.90	0.12	0.02	2.10
	P	0.92	<0.0001*	0.98	0.18	0.73	0.88	0.15
RLES	F	2.19	199.96	0.18	0.14	0.24	0.02	0.04
	P	0.14	<0.0001*	0.67	0.70	0.62	0.88	0.83
LLES	F	0.80	187.30	0.19	1.68	0.01	1.16	0.90
	P	0.37	<0.0001*	0.66	0.20	0.90	0.29	0.35
RRF	F	2.67	0.60	5.22	0.09	0.16	0.30	2.03
	P	0.11	0.44	0.02*	0.76	0.69	0.58	0.16
RBF	F	0.71	47.80	0.005	1.14	0.02	0.01	0.49
	P	0.40	<0.0001*	0.95	0.29	0.87	0.90	0.48
RTA	F	0.46	10.51	10.07	2.72	0.41	7.20	2.31
	P	0.49	0.003*	0.003*	0.11	0.52	0.01*	0.14
Rgast	F	0.009	41.60	8.51	1.20	0.13	13.03	0.30
	P	0.92	<0.0001*	0.006*	0.28	0.72	0.001*	0.58

*Significant P-values

The activity levels of all muscles were significantly greater during the flexi-bar than the QS condition (Figure 1). However, this effect was dependent on the support surface for RTA and RGast activity (significant task×surface interaction) (Figure 2). The results of post-hoc analysis showed that RTA and RGast activity was significantly greater in the flexi-bar than the QS condition on both the foam and rigid surface (Figure 2). In addition, significant

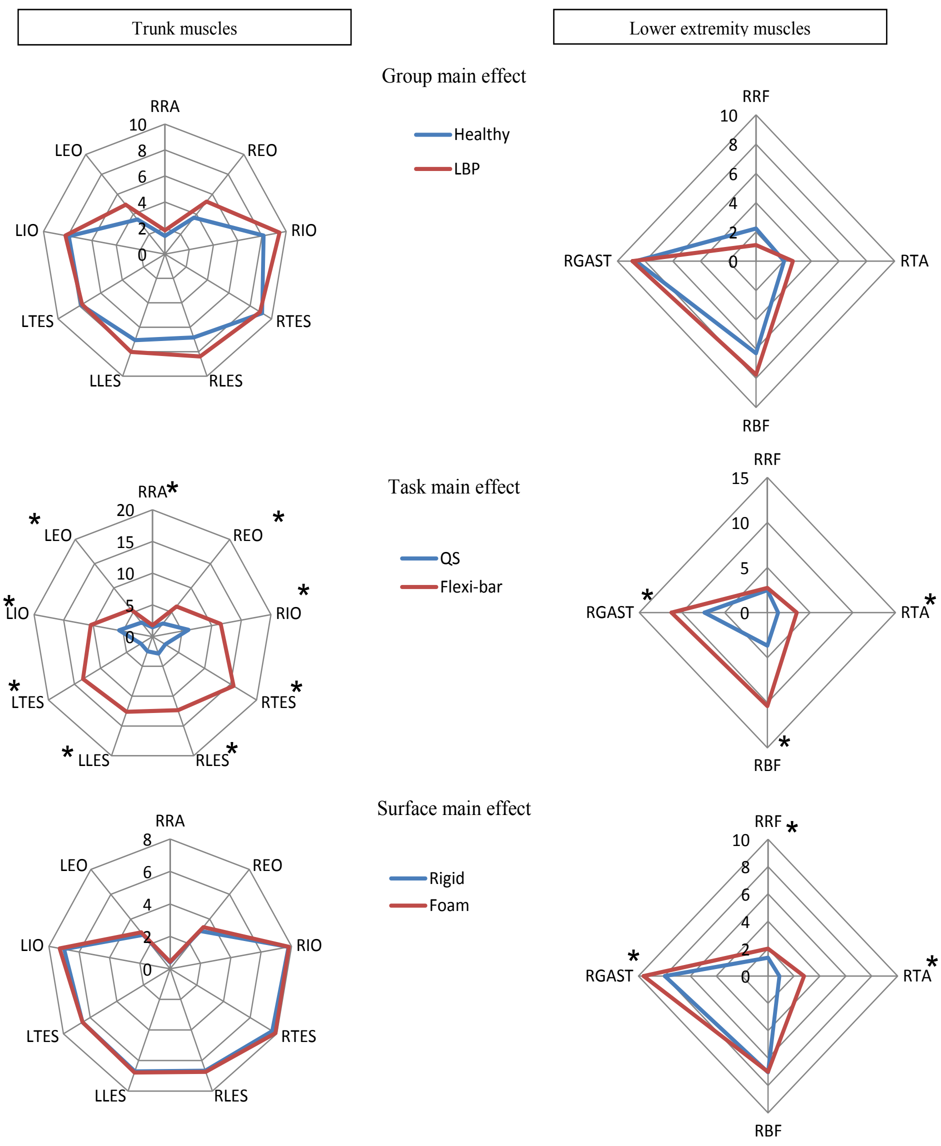

Figure 1: The results of comparing the main effects of group, task and surface in trunk and lower extremity muscles. Values of all axes in each graph are %MVC. (RRA: right rectus abdominis, REO and LEO: right and left external oblique, RIO and LIO: right and left internal oblique, RTES and LTES: right and left thoracic erector spine, RLES and LLES: right and left lumbar erector spine, RRF: right rectus femoris, RTA: right tibialis anterior, RBF: right biceps femoris, RGAST: right gastrocnemius). *Significant differences

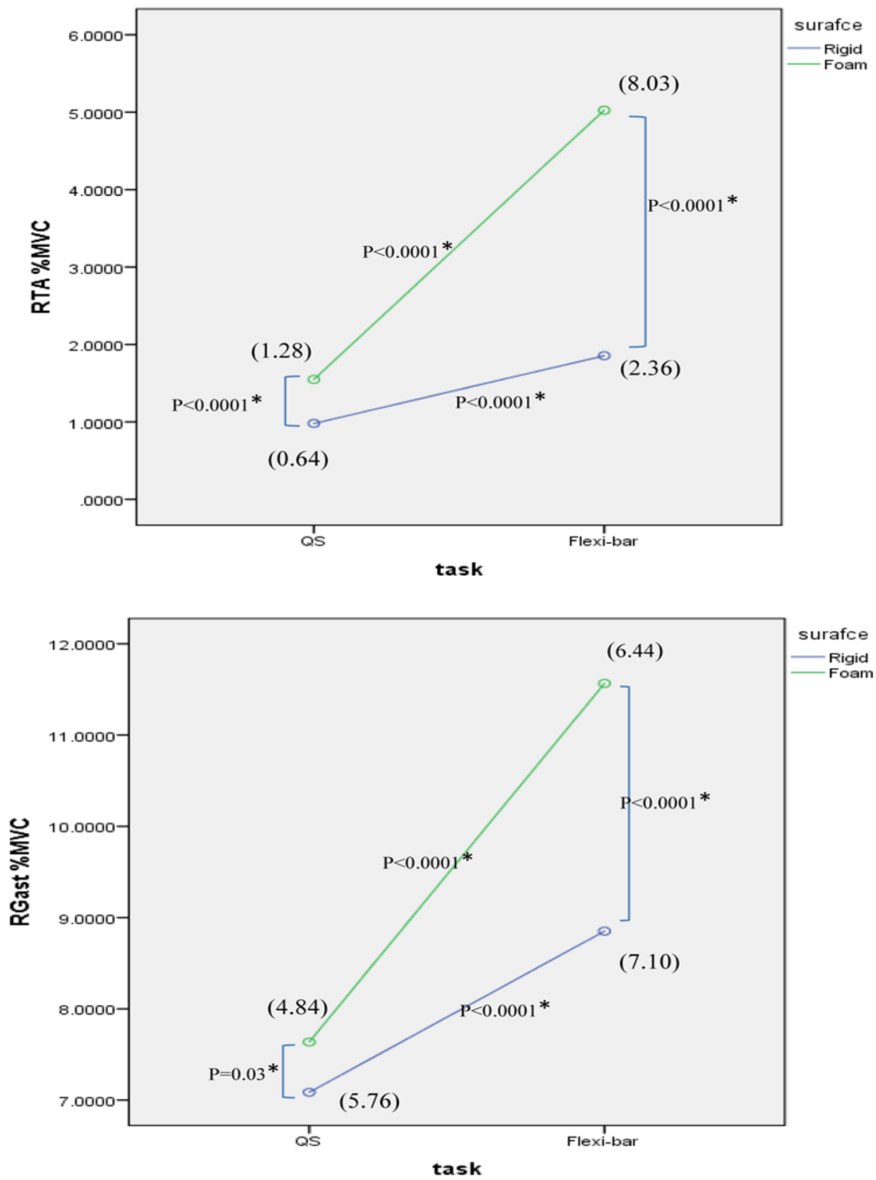

Figure 2: The results of post hoc analysis of surface×task interaction (Wilcoxon/paired-T tests) in the right tibialis anterior and gastrocnemius. Values in parentheses are standard deviations (SD). *Significant differences. QS: quiet stance, RTA: right tibialis anterior, RGast: right gastrocnemius

main effects for support surface were found for RRF, RTA, and RGast activity. The results showed significantly greater muscle activity on the foam than on the rigid surface (Table 5, Figure 1). However, this effect was task-dependent for RTA and RGast (significant task×surface interaction) (Table 5, Figure 2). The results of post-hoc analysis showed that RTA and RGast activity was significantly greater on the foam than on the rigid surface in both the flexi-bar and QS condition (Figure 2).

Discussion

To the best of the authors' knowledge, this study is the first to characterize and compare trunk and lower extremity muscle activity between healthy individuals and those with LBP while they used a flexi-bar, and the differences in activity according to support surface.

No significant differences were found between the LBP and healthy groups. This result might be due to only mild pain intensity on the test day, and to the fact that none of the tests during the procedure caused an increase in pain in any of the participants. The ODI score in the LBP group indicated a minimal degree of disability [24]. Therefore, a possible explanation for our result may be related to the participants' mild clinical pain and disability. Because similar studies are scarce, it was not possible to compare the present results with earlier findings. The unpublished study by Herasi et al. (2015) was the only one that compared trunk muscle activity during flexi-bar use in healthy people and those with LBP. In consonance with the present results, they found no significant differences between groups [25]. Previous studies reported identical postural stability in healthy people and those with LBP in simple test conditions such as QS [16, 26]. It appears that the simple tasks used in the present study were not challenging enough to reveal between-group differences in muscle responses. On the other hand, other tasks tested in the present study included perturbations on an unstable support surface with sight deprivation, which is a complex task. Marras et al. (2004) found that high-stress conditions may create a greater need for control in both healthy individuals and those with LBP [27]. This may account for the smaller between-group differences. The findings of the present study indicated that the flexi-bar may elicit the same strategies in people with LBP as are used by healthy individuals. This, in turn, suggests that it may be safe for clinicians to advise flexi-bar use in the population with NSLBP.

This study showed that almost all evaluated muscle activities increased to control posture during flexi-bar use. The flexi-bar perturbation resulted in postural challenges by applying an added external load to the body, triggering resistance and increased muscle activity. Bervis et al. suggested that the dynamic property of the applied load (a load with continuous changes in force) is another characteristic that could significantly increase challenges to postural stability in addition to the changes in load [28]. Previous studies mostly evaluated muscles at the trunk level, and in consonance with our results, showed a significant increase in rectus abdominis, external oblique, internal oblique, and erector spine activities during flexi-bar use compared to a non-flexi-bar condition [10]. The present study indicated that using the flexi-bar caused a wide range of responses in the trunk, hip, and ankle. The flexi-bar is a training tool that can effectively transfer vibration to the whole body from the upper extremities, thereby enhancing muscle activity at different levels [29]. Based on the results, it appears that the flexi-bar perturbation resulted in increased muscle activity not only at the trunk level but also in other joints in the kinetic chain. Therefore, the flexi-bar may be suggested as an economical tool in terms of time and cost that can simultaneously train many different muscles that are important in postural control.

It is interesting to note that flexi-bar use increased proximal muscle activity much more than ankle muscle activity (Figure 1). Therefore it may favor the use of muscle control in different segments, and elicit greater participation of proximal control. Earlier evidence showed that people with LBP use rigid postural control strategies instead of a flexible multi-segmental strategy [16]. The multi-segmental strategy uses coordinated postural corrections at several joints [30]. Individuals with LBP who do not use a multi-segmental strategy make less use of proximal lumbopelvic-hip control [16]. Therefore, flexi-bar use may be a potent postural control exercise that can train the motor control system to use a multi-segmental strategy with greater participation of proximal control. In this connection, earlier research demonstrated that continuous perturbation could favor the conversion of the ankle postural control strategy to a multi-segmental strategy [31].

This study showed that using a flexi-bar effectively recruited lower extremity activity in addition to trunk muscle activity. This finding may also be useful in lower extremity musculoskeletal problems. In addition, recent evidence suggested that adding core training to lower extremity rehabilitation may be helpful [32]. Therefore, flexi-bar exercising that targets both core and lower extremity muscle activity may be an effective approach in the treatment of lower extremity musculoskeletal problems and should be considered in future studies.

In previous studies, altered neuromuscular control and decreased use of abdominal and back muscles were found in people with LBP; this pattern of activation may lead to spinal instability and consequently to injury [5, 33]. Because all crucial local and global core stabilizer muscles involuntarily resist external forces applied by the flexi-bar, this tool can be used as a core muscle regimen for NSLBP rehabilitation [34]. Also, the approximately equal level of trunk muscle activity on the right and left sides found in the present study indicated that coordinated exercising has the most beneficial effects on spinal stability [12]. An important consideration is that perturbations during flexi-bar use caused cyclic balance disturbances and consequently rapid oscillatory activity within milliseconds, especially in trunk muscles, to maintain stability [11, 34]. The oscillatory nature of this type of exercise may enable it to target neuromuscular and proprioceptive deficiencies in people with LBP [15, 35]. Future studies are needed to investigate this.

In the present study, the use of a foam support surface resulted in higher muscle activity in the RRF, RTA, and RGast compared to the stable surface. However, no changes were found in abdominal and back muscle activities. The significantly greater ankle movement on the foam surface (data not shown) may have resulted in greater use of the leg muscle stretch reflexes, and evidence has shown that these reflexes are still effective on foam surfaces [36]. Accordingly, the greater ankle muscle activity on the foam surface was predictable. This co-contraction may cause joint stiffness to stabilize the center of mass. Notably, in all test conditions vision was occluded, and this condition was suggested to be primarily linked with the ankle strategy [37]. However, the foam surface distorts sensory information and decreases the proprioceptive weight of the ankle [16]. Therefore, as the results indicate, the foam condition required proximal muscle control rather than the use of the surrounding joints and the ankle strategy [16]. It appears that muscle activation at the hip level without any significant increase in abdominal and back muscle activities was sufficient to control balance on the unstable support surface in the present study. Previous studies showed the hip strategy to be the primary resort [38], and also compensatory leg and trunk muscle activity in moving support conditions [39, 40]. Some of the discrepancies with the present findings may be explained by differences in experimental conditions across studies. Nonetheless, the information from this part of the present results may be useful in planning interventions to target specific deficiencies such as impaired hip control in persons with LBP [41]. In this connection Figure (1) shows a lower non-significant RRF activity in people with LBP. The present results thus suggest that using a foam surface may help to train hip muscle activity in people with LBP.

With regard to the differences between using the flexi-bar on a foam or rigid surface, the present results showed that exercising on a foam surface recruited all muscle activities at the same level as on a rigid surface, except for RRF, RTA, and RGast. Flexi-bar exercising on a foam surface placed greater demands on RRF, RTA and, RGast activity. It is worth noting that compared to the QS condition, the flexi-bar condition did not improve RRF activity, whereas the foam surface was associated with greater RRF muscle activity. Therefore, a combination of flexi-bar use on a foam surface may be a potential way to additively enhance hip muscle activation to specifically target hip control deficiency in people with LBP [41].

Both unstable support surfaces and flexi-bar use provide perturbing environments. The foam surface was associated with greater muscle activity only in the ankle and RRF. However, the flexi-bar led to a wider range of responses through the trunk, hip, and ankle to control posture. These findings may indicate that vibration caused by the flexi-bar was a greater challenge that required the participation of more proximal segments for postural control (i.e., trunk and hip level in addition to ankle level) than the foam surface condition (i.e., hip level in addition to ankle level). Therefore, the level of postural muscle control may depend on environmental conditions.

The lower extremity EMG recordings were obtained for one side only because of the limitation in the number of EMG channels. The results of this study are limited to healthy young men and young men with LBP and only mild disability. This study evaluated the effects of flexi-bar oscillation only in the sagittal plane. Future studies should also investigate the effects of flexi-bar use in other planes of oscillation. In view of the potential effects of flexi-bar use and support surface changes based on the present results, future studies should also investigate the effects of long-term flexi-bar exercising in different conditions in a clinical trial study design. This design may help to clarify whether flexi-bar exercising on foam would be more beneficial for clinical outcomes in LBP rehabilitation or not.

Conclusion

The results of this study provide important considerations about the potential effects of oscillatory forces caused by the flexi-bar and different support surfaces on trunk and lower extremity muscle activity in both healthy people and those with LBP, and can consequently guide clinicians in devising LBP rehabilitation programs. In addition, the results indicate that flexi-bar use can effectively increase muscle activation in multiple segments (trunk, hip, and ankle muscles) that are crucial for postural stability. Performing this postural control task on a soft surface seemed to target more proximal rather than ankle control. Therefore, using a flexi-bar may be helpful in LBP rehabilitation, and exercising on a foam surface may favor additive hip muscle activity in people with LBP. This information may help clinicians to use the most appropriate exercise depending on individual therapeutic goals.

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Conflict of Interest

None

References

1. Airaksinen O, Brox JI, Cedraschi C, Hildebrandt J, Klaber-Moffett J, et al. European guidelines for the management of chronic nonspecific low back pain. *European Spine Journal*. 2006;**15**(Suppl 2):s192–s300. doi: 10.1007/s00586-006-1072-1. PubMed PMID: 16550448. PubMed PMCID: PMC3454542.
2. Hancock MJ, Maher CG, Laslett M, Hay E, Koes B. Discussion paper: what happened to the 'bio'in the bio-psycho-social model of low back pain? *European Spine Journal*. 2011;**20**(12):2105-10. doi: 10.1007/s00586-011-1886-3.
3. Stokes IA, Gardner-Morse MG, Henry SM. Ab-

dominal muscle activation increases lumbar spinal stability: analysis of contributions of different muscle groups. *Clinical Biomechanics*. 2011;**26**(8):797-803. doi: 10.1016/j.clinbiomech.2011.04.006.

4. Jacobs JV, Roy CL, Hitt JR, Popov RE, Henry SM. Neural mechanisms and functional correlates of altered postural responses to perturbed standing balance with chronic low back pain. *Neuroscience*. 2016;**339**:511-24. doi: 10.1016/j.neuroscience.2016.10.032.
5. Radebold A, Cholewicki J, Polzhofer GK, Greene HS. Impaired postural control of the lumbar spine is associated with delayed muscle response times in patients with chronic idiopathic low back pain. *Spine*. 2001;**26**(7):724-30.
6. Silfies SP, Squillante D, Maurer P, Westcott S, Karduna AR. Trunk muscle recruitment patterns in specific chronic low back pain populations. *Clinical Biomechanics.* 2005;**20**(5):465-73. doi: 10.1016/j.clinbiomech. 2005.01.007.
7. Newell KM. Motor skill acquisition. *Annual Review of Psychology*. 1991;**42**(1):213-37.
8. Lister JL, Del Rossi G, Ma F, Stoutenberg M, Adams JB, Tobkin S, Signorile JF. Scapular stabilizer activity during Bodyblade®, cuff weights, and Thera-Band® use. *Journal of Sport Rehabilitation*. 2007;**16**(1):50-67. doi: 10.1123/jsr.16.1.50,
9. Schulte RA, Warner C. Oscillatory devices accelerate proprioception training. *Clin Biomech.* 2001;**6**(6):85-91.
10. Sánchez-Zuriaga D, Vera-Garcia FJ, Moreside JM, McGill SM. Trunk muscle activation patterns and spine kinematics when using an oscillating blade: influence of different postures and blade orientations. *Archives of Physical Medicine and Rehabilitation*. 2009;**90**(6):1055-60. doi: 10.1016/j.apmr.2008.12.015
11. Gonçalves M, Marques NR, Hallal CZ, van Dieen JH. Electromyographic activity of trunk muscles during exercises with flexible and non-flexible poles. *Journal of Back and Musculoskeletal Rehabilitation*. 2011;**24**(4):209-14. doi: 10.3233/BMR-2011-0297.
12. Moreside JM, Vera-Garcia FJ, McGill SM. Trunk muscle activation patterns, lumbar compressive forces, and spine stability when using the bodyblade. *Physical Therapy*. 2007;**87**(2):153-63. doi: 10.2522/ptj.20060019.
13. Martins LRGM, Marques NR, Ruzene JRS, Morita ÂK, Navega MT. Electromyographic activity and cocontraction of trunk muscles during exercises performed with an oscillatory pole: an analysis of the effect of different postures. *Fisioterapia e Pesquisa.* 2015;**22**(2):119-25.
14. Anderson K, Behm DG. Trunk muscle activity increases with unstable squat movements. *Canadian Journal of Applied Physiology*. 2005;**30**(1):33-45. doi: 10.1139/h05-103.
15. Borghuis J, Hof AL, Lemmink KA. The importance of sensory-motor control in providing core stability. *Sports Medicine*. 2008;**38**(11):893-916. doi: 10.2165/00007256-200838110-00002.
16. Claeys K, Dankaerts W, Janssens L, Pijnenburg M, Goossens N, Brumagne S. Young individuals with a more ankle-steered proprioceptive control strategy may develop mild non-specific low back pain. *Journal of Electromyography and Kinesiology*. 2015;**25**(2):329-38. doi: 10.1016/j.jelekin.2014.10.013.
17. Lee DK, Kim YN, Park CB, Park MS. The effect of actively induced vibration using shoulder joint on pain and dysfunction in patients with low back pain. *Journal of Physical Therapy Science.* 2018;**30**(1):23-6. doi: 10.1589/jpts.30.23.
18. Chung SH, You YY, Lee HJ, Sim SH. Effects of stabilization exercise using flexi-bar on functional disability and transverse abdominis thickness in patients with chronic low back pain. *Journal of Physical Ttherapy Science.* 2018;**30**(3):400-4. doi: 10.1589/jpts.30.400.
19. Mousavi SJ, Parnianpour M, Mehdian H, Montazeri A, Mobini B. The Oswestry disability index, the Roland-Morris disability questionnaire, and the Quebec back pain disability scale: translation and validation studies of the Iranian versions. *Spine.* 2006;**31**(14):E454-9. doi: 10.1097/01.brs.0000222141.61424.f7.
20. Rostami M, Noorian N, Mansournia MA, Sharafi E, Babaki AE, Kordi R. Validation of the Persian version of the fear avoidance belief questionnaire in patients with low back pain. *Journal of Back and Musculoskeletal Rehabilitation*. 2014;**27**(2):213-21. doi: 10.3233/BMR-130439.

21. Hermens HJ, Freriks B, Merletti R, Stegeman D, Blok J, Rau G, Disselhorst-Klug C, Hägg G. European recommendations for surface electromyography. *Roessingh Research and Development*. 1999;**8**(2):13-54.

22. 22:Mientjes MI, Frank JS. Balance in chronic low back pain patients compared to healthy people under various conditions in upright standing. *Clinical Biomechanics*. 1999;**14**(10):710-6. doi: 10.1016/S0268-0033(99)00025-X.

23. Silfies SP, Cholewicki J, Radebold A. The effects of visual input on postural control of the lumbar spine in unstable sitting. *Human Movement Science.* 2003;**22**(3):237-52. doi: 10.1016/S0167-9457(03)00046-0.

24. Fairbank JC, Pynsent PB. The Oswestry disability index. *Spine.* 2000;**25**(22):2940-53.

25. Herasi M. Evaluation and comparison of trunk muscles activity during two different exercise with flexible pole in young females with and without non-specific low back pain [Dissertation]. Tarbiat Modarres University; 2015.

26. Pijnenburg M, Caeyenberghs K, Janssens L, Goossens N, Swinnen SP, Sunaert S, Brumagne S. Microstructural integrity of the superior cerebellar peduncle is associated with an impaired proprioceptive weighting capacity in individuals with non-specific low back pain. *PLoS One*. 2014;**9**(6). doi: 10.1371/journal.pone.0100666. PubMed PMID: 24949796. PubMed PMCID: PMC4065054.

27. Marras WS, Ferguson SA, Burr D, Davis KG, Gupta P. Spine loading in patients with low back pain during asymmetric lifting exertions. *Spine J.* 2004;**4**(1):64-75. doi: 10.1016/S1529-9430(03)00424-8.

28. Bervis S, Kahrizi S, Parnianpour M, Mobini B. Evaluation of postural stability while holding variable dynamic load in asymmetric postures in healthy men subjects. *Razi Journal of Medical Sciences.* 2012;**19**(105):36-45.

29. De Gail P, Lance JW, Neilson PD. Differential effects on tonic and phasic reflex mechanisms produced by vibration of muscles in man. *Journal of Neurology, Neurosurgery, and Psychiatry*. 1966;**29**(1):1-11. doi: 10.1136/jnnp.29.1.1. PubMed PMID: 5910574. PubMed PMCID: PMC495977.

30. Kiemel T, Elahi AJ, Jeka JJ. Identification of the plant for upright stance in humans: multiple movement patterns from a single neural strategy. *Journal of Neurophysiology*. 2008;**100**(6):3394-406. doi: 10.1152/jn.01272.2007. PubMed PMID: 18829854.

31. Van Ooteghem K, Frank JS, Horak FB. Practice-related improvements in posture control differ between young and older adults exposed to continuous, variable amplitude oscillations of the support surface. *Experimental Brain Research*. 2009;**199**(2):185. doi: 10.1007/s00221-009-1995-y.

32. Foroughi F, Sobhani S, Yoosefinejad AK, Motealleh A. Added value of isolated core postural control training on knee pain and function in women with patellofemoral pain syndrome: a randomized controlled trial. *Archives of Physical Medicine and Rehabilitation.* 2019;**100**(2):220-9. doi: 10.1016/j.apmr.2018.08.180.

33. MacDonald D, Moseley GL, Hodges PW. People with recurrent low back pain respond differently to trunk loading despite remission from symptoms. *Spine.* 2010;**35**(7):818-24. doi: 10.1097/BRS.0b013e3181bc98f1.

34. Anders C, Wenzel B, Scholle HC. Activation characteristics of trunk muscles during cyclic upper-body perturbations caused by an oscillating pole. *Archives of Physical Medicine and Rehabilitation.* 2008;**89**(7):1314-22. doi: 10.1016/j.apmr.2007.11.047.

35. Clark NC, Röijezon U, Treleaven J. Proprioception in musculoskeletal rehabilitation. Part 2: Clinical assessment and intervention. *Manual Therapy.* 2015;**20**(3):378-87. doi: 10.1016/j.math.2015.01.009.

36. Chiang JH, Wu G. The influence of foam surfaces on biomechanical variables contributing to postural control. *Gait & Posture.* 1997;**5**(3):239-45. doi: 10.1016/S0966-6362(96)01091-0.

37. Singh NB, Taylor WR, Madigan ML, Nussbaum MA. The spectral content of postural sway during quiet stance: influences of age, vision and somatosensory inputs. *Journal of Electromyography and Kinesiology*. 2012;**22**(1):131-6. doi: 10.1016/j.jelekin.2011.10.007.

38. Gatev P, Thomas S, Kepple T, Hallett M. Feedforward ankle strategy of balance during quiet stance in adults. *The Journal of Physiology.* 1999;**514**(3):915-28. doi: 10.1111/j.1469-7793.1999.915ad.x.

39. Fransson P-A, Gomez S, Patel M, Johansson L. Changes in multi-segmented body movements and EMG activity while standing on firm and foam support surfaces. *Eur J Appl Physiol.* 2007;**101**(1):81-9. doi: 10.1007/s00421-007-0476-x. PubMed PMID: 17503068.

40. Sousa AS, Macedo R, Santos R, Tavares JMR, editors. Influence of an unstable shoe on compensatory postural adjustments: An experimental evaluation. TMSi-Sixth International Conference on Technology and Medical Sciences; CRC Press;2010. p. 279-84. doi: 10.1201/b11330-52.

41. Mok NW, Brauer SG, Hodges PW. Postural recovery following voluntary arm movement is impaired in people with chronic low back pain. *Gait & Posture*. 2011;**34**(1):97-102. doi: 10.1016/j.gaitpost.2011.03.021.