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A Systematic Review

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Core muscle activity assessed by electromyography during exercises for chronic low back pain: a systematic review.

Core EMG activity during exercises for CLBP

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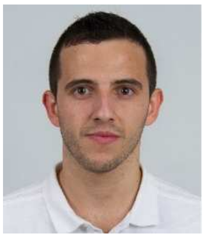

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Abstract

Low back pain (LBP) is one of the most frequent health problems worldwide affecting both work and personal life. While physical exercise focusing on the core muscles is commonly used as part of treatment, there is no systematic overview of exercise specificity and intensity among people with chronic LBP (CLBP). This manuscript aims to systematically review the literature on core muscle activity assessed by electromyography (EMG) during exercises in adults with non-specific CLBP. This systematic review serves as a reference guide in the selection of core muscle exercises for non-specific CLBP.

Keywords: electromyography; exercise; motor control; physiotherapy; rehabilitation; spine; trunk.

Abstract word count: 91

Introduction

Low back pain (LBP) is one of the most frequent health problems worldwide with a lifetime prevalence of up to 84% (66). LBP occurs in all stages of life, although with lower prevalence before adolescence and a decrease in the onset of new episodes in the last decade of life (35). Although most cases of acute pain subside spontaneously by the effect of natural history (49), most people experience at least one episode of recurrence (31,61). In approximately 20-30% of cases the pain can be persistent and disabling, limiting activity in sports, work and social life (35). High intensities of LBP gradually increase the risk for long-term sickness absence from work (1). For this reason, LBP is the leading cause of disability in people less than 45 years of age and the most costly in people aged 20 to 57 years (35).

There are many different classifications of LBP, often based on duration and cause. In terms of duration, chronic LBP (CLBP) can be defined as pain persisting for at least 12 weeks in the area between the lower rib and the gluteal fold(3,9,54). In terms of cause, multiple etiologies such as radicular problems or osteoarthritis may be the origin of the patient's symptomatology. Thus, clinical classifications have been used to help in managing patients with LBP (55,56).

Chronicity and disability of LBP have increased despite the significant increase of investment in research, radiological imaging, treatment, and medication (8). In the United States, opioids are the most prescribed type of drug for back pain (36). However, opioids are associated with a number of adverse effects, complications, and fatal overdoses (52). Nevertheless, there is no evidence that use of opioids improves return to work or reduces the need for other treatments (21). In addition, a recent systematic review showed that real surgery is no better than sham surgery for CLBP (38). For these reasons, researchers and clinicians have during the last decade made an effort to change the paradigm of LBP, looking for possible causes and implementing new treatment approaches.

Regarding the causal mechanisms, several differences exist between patients with and without CLBP, for example, in morphology and electromyographic (EMG) activity of the core muscles. Motor control impairments have been found in patients with LBP, with a delayed EMG timing response (14) and altered patterns of muscle recruitment (16,57). Alterations in trunk EMG activity have been found in patients with CLBP during daily activities and exercises compared to healthy adults (13,22) . Moreover, patients with CLBP generally have lower lumbar extension strength (11,58), reduced paraspinal muscle cross sectional area (18,40), higher fat infiltration and changes in the ratio of muscle fiber types (44,68), and higher levels of perceived fatigue compared to healthy subjects (47). Some researchers and clinicians have suggested that the lumbar multifidus, transversus abdominis, and quadratus lumborum could be the most impaired among the trunk muscles, reporting associations between LBP and dysfunction of these muscles (29,32–34).

Among the many available options, active exercise is one of the most used treatments (43). Specifically, lumbar stabilization training has been used extensively for the management of LBP. This type of training aims to activate deep and superficial spinal muscles (7) and to achieve an adequate trunk position above pelvis structure to favor the movement and the energy transfer from the distal segments of the limbs (12). Using such training, therapists aim to improve neuromuscular control and recruitment, improving the ability to perform daily life activities and indirectly reducing pain and disability. However, a wide variety of exercises (e.g., dynamic or isometric) and complementary techniques (e.g., bracing maneuver) exists. For this purpose, proper exercise selection is a key aspect to provide progressive neuromuscular challenges for the muscles of interest.

Surface EMG is commonly used to assess levels of muscle activity and patterns of recruitment (65). During recent years, researchers have evaluated EMG of the core muscles in exercises commonly performed by patients with LBP. However, most of the studies used healthy participants (15,17,23–26,28). Because EMG activity is different in subjects with and without LBP, no systematic overview of EMG activity during such exercises in patients with LBP exists. However, such information is important for improving clinical decision-making with objective data to select appropriate exercises for each specific muscle, at each training session or stage of treatment, as well as the possibility of creating new management and prevention strategies.

The aim of this study was to systematically review the literature evaluating EMG activity of commonly used muscles in exercises for CLBP.

Methods

Search

Between October 2016 and February 2017 an electronic search was conducted by three researchers using PubMed, PEDro, ScienceDirect, Embase, Sport Discus and Proquest Central databases for English-language studies published after January 1, 2001. For this purpose, an adaptation of the terms specified in Table 1 was used considering the characteristics of each search engine. Furthermore, a manual search was performed based on the references cited in the located articles. Additionally, a search about physical exercise and LBP was carried out using the Cochrane Library. Only full-text articles written in English were included.

[Table 1 near here]

Selection

Although descriptive studies about EMG of exercises were searched for, other types of studies were not ruled out. Interventions recording EMG in exercises prior to initiation of the program were included. Selection criteria used for the systematic review are shown in Table 2.

[Table 2 near here]

After deleting duplicated results, one author screened the titles and abstracts and excluded irrelevant studies. Two other authors analyzed the full-text of the remaining studies to verify compliance with the selection criteria. In case of doubt, the three authors met and discussed the paper until agreement was reached.

Normalized EMG (nEMG) activity classification

We classified exercise intensity based on the level of nEMG:

- Low muscle nEMG activity: <20%
- Moderate nEMG activity: 20-40%
- High nEMG activity: 41-60%
- Very high nEMG activity: >60%

Methodological quality assessment

To our knowledge, there is no standard scale to assess the methodological quality of observational studies using EMG (53). However, in an effort to judge the quality of the included studies, some items of the Effective Public Health Practice Project (EPHPP) quality assessment tool were used, as other authors did in a similar type of review (46). The EPHPP quality assessment tool subjectively classify the studies to strong, moderate, or low quality (19,37). The nine items assessed are study design, selection bias, blinding, confounders, data collection methods, withdrawals and dropouts, intervention integrity, and analysis. According to the GRADE system, in observational studies, confidence and quality are reduced when one or more of the following occur: wrong selection criteria of the population, inadequate measures of exposure or outcome, inadequate control of confounding factors or incomplete follow-up of the patients (59).

Accordingly, due to the type of studies included in the present systematic review, only 1) selection bias, 2) data collection, and 3) reporting of data were evaluated. The first two elements were assessed according to the instructions of the EPHPP tool. Reporting of data was considered weak if important procedures or results were not described, moderate if all the important information was reported but inaccurately, and strong if the data reporting procedures were correct. Likewise, the quality of the studies was globally rated as strong when none of the sections were rated as weak, moderate when there was one section rated as weak, and weak when there were two or more sections considered as weak. We recommend these criteria to be included in future systematic reviews of EMG during exercises.

RESULTS

Search results

Five studies were included based on the manual search. In total, 1653 studies were found by means of the search process. After deleting duplicates, the search yielded 756 studies. Based on screening of titles and abstracts, 117 studies were potentially relevant. After screening full-text articles, a total of eight studies were included in the systematic review (3,20,39,41,42,45,51,67). Seventy-seven studies were deemed ineligible. Reasons for exclusion were non-relevance of the study or non-compliance with the election criteria. Figure 1 shows graphically this process by means of a flowchart.

[Figure 1 near here]

Included studies

Characteristics of included studies

In total, 105 subjects were enrolled in the 8 included studies. The average ages ranged between 23.0 and 49.7 years. There was a predominance of studies assessing only women. Body Mass Index (BMI) ranged between 21.4 and 25.1 kg/m^2. Kim et al. (42) did not show the BMI of the sample. Overall, the predominant patient type of the present review is the young adult woman.

Included exercises

Several exercises have been used for strengthening the back muscles, both in relation to health and performance. In this systematic review, 48 exercises were included. However, some were repeated exercises or variants of the same exercise. The quadruped opposite arm-leg raise and prone hip extension are two examples of these kinds of exercises, and both were evaluated in several of the included studies. Table 3 shows the exercises evaluated in each study and the muscles analyzed with EMG.

[Table 3 near here]

nEMG activity results

Reporting normalized values of the muscle EMG activity is a minimum requirement for the study election. However, Oh (51) only presented the values that the authors considered interesting for their hypothesis discussion, being able to obtain only half of the muscle activity data recorded in this study. Furthermore, in two articles (3,39) the results were not shown with numerical values, impeding the extraction of EMG values.

For this reason, data were included in the review by means of percentages. Seven studies (20,39,41,42,45,51,67) expressed the maximum voluntary isometric contraction (MVIC), a standardized, objective, and sensitive tool for the measurement of muscle activity. Kim et al. (41) expressed the EMG activity by means of a submaximum voluntary isometric contraction to normalize the absolute EMG amplitudes of two of the muscles analyzed (gluteus maximus and erector spinae), claiming that a maximal contraction of this musculature could have exacerbated the symptomatology. By contrast, Arokoski et al. (3) normalized muscle activity of each exercise to the maximal EMG amplitude obtained during a maximal voluntary dynamic contraction of the back and abdominal muscles using an isokinetic device. Table 4 shows the nEMG activity recorded for each muscle in the studies included in the review.

[Table 4 near here]

Analyzed muscles

External oblique

The EMG activity of the external oblique was analyzed in four studies (3,20,45,67), recording the EMG activity of the musculature in different shoulder and hip movements, the bridge exercise, and the side bridge. The highest nEMG activity was found in the side bridge performed with abdominal bracing (115.1% ± 13.4) (45), followed by the side bridge (108.9% ± 12.6) (45). The lowest nEMG activity was observed in the squat (8.1% ± 4.9, 12.1% ± 2.9) (20,45).

Rectus abdominis

Four studies (3,20,45,67) evaluated the EMG activity of the rectus abdominis. The highest values were found in the side bridge performed with abdominal bracing (57.1% ± 9.5) (45) and in the resisted upper-extremity extension while standing (50-55%) (3). The lowest value was registered using handheld weights and alternating shoulder flexion while sitting straight (0-5%) (3) or standing (0-5%) (3), handheld weight and alternating shoulder flexion while standing straight on the balance board (0-5%) (3), the backward and forward rocking in an elevated sitting position (0-5%) (3), and the hip bridge exercise (0-5%) (3).

Erector spinae

The EMG activity of the erector spinae was analyzed in five studies. However, different positions of electrode placement on the back were used. Desai and Marshall (20) and Marshall and Desai (45) positioned the electrodes around L4-L5, Oh (51) and Kim et al. (41) around L1 of the erector spinae, whereas Kim et al. (42) did not describe the exact position. At L4-L5, the highest nEMG activity was obtained in the side bridge performed with abdominal bracing (63.2% ± 11.0) (45). The highest nEMG activity found at L1 was obtained in the prone hip extension (51.87% ± 11.69) (51).

In two studies, conditions of instability and use of complementary techniques like abdominal bracing obtained higher values than when performed under normal conditions, except for the squat, where conditions of instability obtained lower nEMG activity than conditions of stability (20,45). Moreover, in two other studies, exercises performed with complementary techniques and tools, like a pelvic belt (41) or a visual biofeedback with a laser pointer fixed to a pelvic strap (42), obtained lower nEMG activity of the erector spinae than the same exercises performed without those tools.

Lumbar multifidus

Three studies analyzed the EMG activity of the lumbar multifidus. Arokoski et al. (3) and Yoon et al. (67) recorded the EMG activity by placing the electrodes at the vertebral level L5. However, Jung et al. (39) recorded the signal laterally to the midline of the trunk and above the line connecting both the posterior superior iliac spines. The highest value was obtained in the bilateral leg extension while prone (70-75%) (3) and in the unilateral knee extension while keeping hips in the bridged position on a soft ball (65-70%) (3). The lowest value was registered in the resisted upper-extremity extension while standing (5-10%) (3) and in the transversus abdominis exercise (5-10%) (3).

Internal oblique

Only two studies analyzed the EMG activity of the internal oblique. Comparing some exercises of core stability performed in conditions of instability, Jung et al. (39) showed greater muscle activity of the internal oblique in the plank (30.10% ± 6.22) than in the bridge exercise (9.81% ± 6.68) , both performed using an unstable surface. Yoon et al. (67) reported higher levels of muscle activity when quadruped opposite arm-leg raise were performed than when the same exercise were performed with arm or leg elevation.

Thoracic part of the iliocostalis lumborum

The EMG activity of the thoracic part of the iliocostalis lumborum was evaluated in the same studies that included the internal oblique. In this case, quadruped opposite arm-leg raise produced the highest nEMG activity (40-60%) (67). Comparing exercises performed in conditions of instability, the plank obtained a lower nEMG activity (11.16% ± 7.40) (39) than the bridge exercise (25.23% ± 11.05) (39), both performed in conditions of instability.

Gluteus maximus

Three studies evaluated the EMG activity of the gluteus maximus performing different exercises. Oh (51) and Kim et al. (41) compared the prone hip extension with and without a pelvic compression, obtaining an nEMG activity slightly lower when the exercise was performed with the pelvic belt (24.18% ± 7.59 and 27.24% ± 10.59) (41,51) than when performed without (30.31% ± 14.22 and 33.31% ± 16.65) [46,47]. Kim et al. (42) registered higher nEMG activity of the gluteus maximus in the bridge exercise using trajectory exercises by using a laser pointer fixed to a pelvic strap (28.6% ± 18.0) (42) than without using them (21.3% ± 12.9) (42).

Methodological quality

One study showed weak methodological quality and seven studies showed moderate methodological quality. None of the studies showed high methodological quality. Table 5 shows the results of the applied methodological evaluation scale.

[Table 5 near here]

DISCUSSION

The main purpose of this paper was to systematically review the literature evaluating core muscle activity assessed by EMG in common LBP rehabilitation exercises, using patients with CLBP. An important discovery was that only few studies evaluated muscle EMG activity in patients with CLBP during typical rehabilitation exercises.

Some authors have shown associations of LBP with a dysfunction of the lumbar multifidus, the quadratus lumborum, and the transversus abdominis (29,34). Interestingly, none of the studies included in this review measured EMG activity of the quadratus lumborum or the transversus abdominis. This finding is in line with a similar systematic review published by Martuscello et al. (46), who reviewed studies evaluating exercises routinely used for the treatment of LBP among healthy subjects. In that review, the authors did not find any studies analyzing quadratus lumborum EMG activity and only found few studies evaluating transversus abdominis EMG activity. A plausible reason may be the difficulty in measuring deep muscles with surface EMG. For example, some authors measured the lumbar multifidus with surface EMG, although a previous study showed that surface EMG values do not clearly reflect the activity of the muscle, being instead associated with the adjacent longissimus muscles (62).

Core stability exercises are usually performed isometrically, for example, by using bridging exercises or planks, which activate superficial muscles (10,45) and deep core musculature (mainly responsible for the maintenance of the stability during the movement) (46). For example, the side bridge exercise (performed with abdominal bracing) showed the highest activity of all exercises for three important muscles: external oblique, rectus abdominis, and erector spinae (45). An important part of the core stability exercises analyzed in this review showed low or moderate activity of the rectus abdominis (3,20,42,45,67), except for the side bridge that achieved high (55.0% ± 23.4) (20) and very high (60.5% ± 6.8) (45) nEMG activity. However, the same exercises showed higher activity for the external oblique, the erector spinae, and especially the lumbar multifidus (3,20,45). The plank exercise (prone bridging exercise) has been widely studied and generates high nEMG activity for the rectus abdominis in healthy subjects (10,27). However, only one study analyzed a unique variation of the exercise performed in conditions of instability for CLBP, showing high rectus abdominis activity (42.1% ± 18.59) (39), moderate internal oblique activity (30.1% ± 6.22) (39), and low lumbar multifidus activity (12.05% ± 11.02) (39).

The results of the included studies showed low nEMG activity of the rectus abdominis in the lower and upper limbs exercises examined, except for the resisted upper-extremity extension while standing. However, nEMG activity of the external oblique, lumbar multifidus, and erector spinae were generally moderate or high in this modality of exercises (3,20,45). Exercises like the bilateral prone hip extension showed very high nEMG activity of the lumbar multifidus when were externally resisted (70-75%) (3) and high nEMG activity when not externally resisted (55-60%) (3). Regarding the gluteus maximus, only two exercises (prone hip extension and supine bridging) and their variants were analyzed in the included studies. Previous studies in healthy subjects found high muscle activity of gluteus maximus in the side plank with hip abduction, the single limb squat, and the clamshell exercise (hip clam) (6). This finding suggests that these exercises could also be used to efficiently activate the gluteus maximus muscle in subjects with CLBP, although future studies should corroborate this.

A recent systematic review published by Martuscello et al. (46), reported that the squat, deadlift and lunge exercises provided moderate to very high lumbar core muscle activity in healthy subjects, especially when external loads were added. Interestingly, we found few studies using external loads, and these studies reported absolute loads. For instance, a previous study (3) used a shoulder flexion exercise with dumbbells (women, 1kg; men, 2kg). Another exercise that is typically external-resisted is the squat, although only two studies were found with patients with CLBP (20,45) and the exercise was performed isometrically, with body weight as resistance. The later exercise showed low nEMG activity of the rectus abdominis and the external oblique (20,45) and moderate (20) or high (45) nEMG activity of the erector spinae. However, even though the squat is a dynamic exercise, performing it isometrically may limit extrapolation of the results. Future studies evaluating the dynamic squat in patients with CLBP are warranted, because this provides high transference to basic daily activities. Surprisingly the deadlift and the lunge were not analyzed in the included studies, in spite of existing literature showing promising results of including these exercises in rehabilitation of LBP patients (5). Future studies should evaluate such exercises for safety and efficacy among patients with CLBP. In healthy adults, the use of external loads induce higher levels of core muscle EMG activity than exercises without added external load (50). However, studies evaluating muscle EMG activity with externally-loaded exercises in patients with CLBP are scarce. One possible reason for the lack of studies investigating the EMG activity in exercises with external loads in subjects with pain, could stem from the belief of some authors in a possible relation between intensity (i.e., high EMG values) and risk of injury or pain in this population (3). For example, some authors suggested that muscle activity levels higher than 40% of the MVIC could be counter-productive because of the increased risk of injury (3). In contrast, it seems plausible use external loads in patients with CLBP (performed with proper technique), especially in more advanced phases of the program, where motor control and stability allow greater loads. In fact, the use of external loads does not necessarily result in high intensity. Actually, the use of external loads can provide greater individualization, variation and facilitates progressive neuromuscular challenges which are three basic training principles. Thus, by using external loads, exercises can be easily dosed in a controlled manner, something difficult to achieve in e.g. the isometric plank, which is more dependent on bodyweight and exercise posture.

Training in conditions of instability is characterized by exercises performed with devices or postures challenging postural control. This kind of resistance training has been a hot topic during the last decades. On one hand, in healthy young subjects, authors have reported that such training facilitates recruitment of muscle fibers for maintaining body stability, reducing force production, and limiting performance on stable environments (4,60). These findings agree with the high nEMG activity obtained by the instability exercises included in the present systematic review. On the other hand, previous studies have shown increased compressive loads of the lumbar spine in some exercises performed in conditions of high instability, e.g. during suspension training (48). These findings should be considered in subjects with a history of weakness of the erector spinae or segmental spinal instability. Thus, performing exercises in conditions of instability can increase the level of muscle activity as well as exercise complexity without the need to use external loads. However, the interpretation of the results should be made with caution, considering that higher EMG activity will not always be directly related to an increase in strength gains. Importantly, when comparing the same exercise performed in conditions of stability or instability with the same absolute load, the relative load will be greater in conditions of instability. Therefore, proper EMG comparison of unstable/stable exercises should be conducted using the same relative load (i.e., calculated on each different condition). When this is not possible, it is necessary to take this into account for the interpretation of the results.

The present systematic review also showed that the use of complementary techniques and tools have different effects depending on each exercise and technique. Use of visual feedback like a laser pointer during the execution of the bridge exercise showed different effects on the EMG activity depending on the musculature analyzed. For example, the nEMG activity of the gluteus maximus and hamstrings increased while the nEMG activity of the erector spinae decreased, comparing the same exercise with and without the laser pointer in people with CLBP (42). According to this finding, directing the attention to the exercises has the potential to increase the nEMG activity of some muscles. By contrast, use of pelvic belt as a compression mechanism decreased nEMG activity of the gluteus maximus, the erector spinae, the biceps femoris, and the latissimus dorsi in two of the included studies (42,51). This finding may be clinically relevant, as previous studies reported higher nEMG activity of the trunk and hip musculature during the prone hip extension in patients with CLBP (2). This technique could be useful in early stages where good stability and control is the focus. The abdominal bracing is a technique based in the active contraction of the abdominal muscles during the exercises. This maneuver has been used in some studies to improve lumbar stabilization. In previous studies, when comparing two stabilization maneuvers such as abdominal bracing and abdominal hollowing, the abdominal hollowing maneuver did not improve stability (30,63). Conversely, the abdominal bracing maneuver stimulated torso co-contraction, minimized lumbar displacement, and improved trunk stability, but generating spinal compression (63). However, in the same study, it was found that when participants knew the timing of perturbation, they were able to stabilize their trunk, resulting in smaller compressive loads in the lumbar spine (63). These findings obtained in healthy subjects should be studied and corroborated in an adequate sample of patients with CLBP. In this review, only one study used the abdominal bracing technique, obtaining an important nEMG activity increase, achieving increases of nEMG similar to those obtained during instability conditions (45).

Three studies of this review (20,41,45) included a healthy sample to compare the EMG values of the exercises between these subjects and those with CLBP. In a previous study, van Dieën et al. (22), concluded that findings in the EMG of the trunk muscles in patients with LBP are not concordant with the pain-spasm-model or the pain-adaptation model. The authors proposed that the changes observed are task-dependent and related to each individual problem and, for this reason, a high variability between individuals exists. Findings described in the included studies in this review are in accordance with this explanation. Desai and Marshall (20) and Marshall and Desai (45) shared the conclusion that pain-induced increases of nEMG is not seen in all muscles and exercises, but are produced by adaptive strategies in the form of increased or decreased nEMG activity to achieve an optimal execution adapted to the specific pain condition. It is unknown whether these adaptations are cause or consequence of the pain. For this reason, adequate training of the core muscles and the neuromuscular system may be beneficial for restoring the capacity of the musculoskeletal system to perform movements efficiently and painlessly.

The main limitation of this review is the heterogeneity of methods between studies to normalize EMG values. Although we only included studies using normalization procedures, either dynamic or isometric, the many different criteria and methods for normalizing introduces a number of biases when comparing between studies. For example, inadequate procedures or other factors such as normalization technique, data analysis, or simply not achieving a true maximal effort may produce inconsistencies in the calculated percentages. In addition, heterogeneity in electrode placement between studies must be considered. In this context, a quite similar electrode placement were used, for example, for two different muscles such as the lumbar multifidus (3) and the erector spinae (20,45). Finally, cross-talk when measuring deep muscles with surface EMG remains reduces the reliability of the values provided. The lack of knowledge about EMG activity of deep musculature during common exercises in both healthy people and patients with CLBP limits the evidence-based prescription of such exercises. Another limitation of this review is the scarcity of studies focusing on this topic, and among some of them, the limited reporting of data. The methodological quality of the published studies was in general moderate. Although the quality assessment tool of the present review has not been designed to evaluate this type of studies, the difficulty in evaluating methodological quality shows the necessity of unifying methodological criteria. The criteria shown in the present systematic review can be a step forward to standardize the systematic evaluation of EMG exercise studies.

Conclusions

The present systematic review evaluating nEMG activity during various modalities of exercises with different characteristics can be used as a reference guide when prescribing progressive exercise programs for patients with CLBP. A single modality of exercise may not be adequate to improve physical condition and function in these patients. Among the exercises included in this review we found exercises with low, medium, high, and very high nEMG values. The data provided can be used to individualize programs and attend to the progression training principle, selecting the exercises according to levels of muscle activity and individual tolerance.

Performing exercises in conditions of instability could be a good way to increase the demand of the neuromuscular system, although the characteristics of this type of training should be taken into account. Knowing that this kind of exercises hinders the maintenance of stability and increases the trunk movements (64), avoiding them in the early stage of rehabilitation may be advisable.

In previous studies, the abdominal bracing has been shown to produce good stability (measured by the Spine Stability Index in Nm/rad), being up to 32% more effective than abdominal hollowing (30). For this reason, its use may be recommended in intermediate phases of the program, combining a high nEMG activity with the maintenance of stability. Differently, use of a visual feedback during exercises seems to change positively the pattern of movement. In general, using techniques and tools to influence the technique of execution and motor learning seems relevant.

The present systematic review also showed a gap in the literature. The use of external loads should be studied in subjects with CLBP because of their potential effect shown in healthy adults, especially in upper and lower limb exercises. The range of nEMG activities obtained with upper and lower limb exercises suggests the use of such exercises in different phases of the program for optimal versatility and progression.

Practical applications

The results of the present systematic review can be used by therapists and clinicians as a guide to generate progressive programs based on the extent of nEMG core muscle activity. The following progressions can serve as an example for each muscle studied:

- External oblique: as a first step, exercises like the isometric squat, the backward and forward rocking in high sitting, or the shoulder flexion with low external loads should be selected. After that, the quadruped opposite arm or leg raise or the weights in hands and altering shoulder flexion with low external loads while standing straight exercise could be the next step. The resisted upper-extremity extension or adduction while standing could be the third step. Then, the side bridge performed with abdominal bracing or on a labile surface could be good exercise options to induce very high levels of muscle activity.
- Rectus abdominis: the backward and forward rocking in high sitting exercise, the transversus abdominis exercise, or the quadruped opposite arm and leg raise could be selected as a first step. For medium muscle activity, the modified push-

up with abdominal bracing would be a good option. The side bridge with or without abdominal bracing, the resisted upper-extremity extension while standing, or the unstable prone bridging exercise could be an option in advanced phases of the program.

- Erector spinae: as a first step, the quadruped arm and leg raise followed by its unstable variation, the side bridge, the isometric squat, or the shoulder flexion with low external loads could be good exercises. The prone hip extension performed with pelvic compression followed by the same exercise performed without pelvic belt or the supine bridging exercise would be selected to intermediate phases. The side bridge with abdominal bracing or performed on a labile surface would be exercises for advanced phases.
- Lumbar multifidus: for initial phases, exercises like the resisted upper-extremity extension while standing or the transversus abdominis exercises could be selected. There is a gap in the exercises studied in CLBP for the intermediate phases in the lumbar multifidus. In advanced phases, the bilateral leg extension while prone or the unilateral knee extension while keeping hips in the bridged position on a soft ball could provide very high values of muscle activity.
- Internal oblique: a progression from the supine bridging on unstable surface and the quadruped arm or leg raise to the prone bridging on unstable surface or the quadruped opposite arm-leg raise could be used.
- Thoracic part of the iliocostalis lumborum: a progression from the prone bridging to the supine bridge exercise performed both on an unstable surface, followed by the quadruped opposite arm-leg raise could be an example of progression.

- Gluteus maximus: a progression from the prone hip extension performed with pelvic compression to the same exercise performed without the pelvic belt could be used. Another progression could be performed from the prone hip extension to the same exercise performed with a laser pointer.

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Declaration of Interests

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Figure legends

Figure 1. Flow chart of the selection process.

CLBP = chronic low back pain, EMG = electromyography.

Table 1. Terms used on the electronic search.

Box I (all fields) (AND)	Terms and variants about target population (low back pain OR LBP OR CLBP OR chronic low back pain OR lumbopelvic pain).
Box II (all fields) (AND)	Terms and variants about the evaluation performed (electromyograph* OR surface electromyography OR myoactivity OR activation OR biofeedback OR myoelectrical OR neuromuscular OR EMG).
Box III (all fields) (AND)	Terms and variants about exercises and physical EMG activity (exercise* OR flexion OR extensión OR rotation OR lateral OR stabiliz* OR therapeutic program OR exercise th* OR physical training).
Box IV (all fields) (AND)	Terms and variants about trunk muscles (core OR multifid* OR lumbar* OR transversus abdominis OR erector spinae OR longissimus OR internal oblique OR external oblique OR paraspinal* OR extensor* OR rectus abdominis OR quadratus lumborum).
Box V (NOT)	Terms and variants that are not of interest for the search (manual therapy OR pharmacological).

LBP = low back pain, CLBP = chronic low back pain, EMG = electromyography.

Table 2. Selection criteria

Inclusion criteria	Studies that recorded the muscular EMG activity of muscles of the core with surface EMG in subjects during physical exercises. Sample of patients with non-specific CLBP lasting at least 3 months. Report of EMG activity normalized as a percentage of a maximal voluntary contraction, either dynamic or isometric. Full text available in English. Published after January 1, 2001.
Exclusion criteria	CLBP classification criteria different from the criteria described in this review or selection criteria not specified. Studies that did not analyze any muscle in the lower back. Sample with root nerve compression, herniated disc, spondylarthrite, previous surgery or another serious cause of LBP. Reviews and case studies.

EMG = electromyograph, CLBP = chronic low back pain, LBP = low back pain.

Table 3. Characteristics of electromyographic analysis.

Authors, year	**CLBP sample (total)**	**Exercises**	**Analyzed muscles**	**Report of values**
Arokoski et al. (4)	N= 20 (40).	18 exercises: Ex.1 Walking on a trampoline, Ex.2 Leg swinging while standing, Ex.3 Weights in hands and altering shoulder flexion while standing straight, Ex.4 Weights in hands and altering shoulder flexion while standing straight on the balance board, Ex.8 Resisted upper-extremity extension while standing, Ex.9 Resisted upper-extremity flexion while standing, Ex.10 Resisted upper-extremity adduction while standing, Ex.5 Weights in hands and altering shoulder flexion while sitting straight, Ex.6 Backward and forward rocking in high sitting, Ex.7 Unilateral leg extension with upper body prone on the board, Ex.17 Resisted bilateral leg extension while prone, Ex.18 Bilateral leg extension while prone, Ex.11 Contralateral arm and leg lift in the all-fours position, Ex.15	RA, EO, MF (L5)	% Maximal Voluntary Dynamic Contraction

		Transversus abdominis exercise, Ex.13 Pushing bent knees against a soft ball in crook lying, Ex.12 Lifting hips up to a bridged position, Ex.14 Unilateral knee extension while keeping hips in a bridged position, Ex.16 Unilateral leg lift against resistance while lying on 1 side.		
Desai & Marshall (23)	N= 10 (20).	10 exercises: quadruped (quadruped opposite arm-leg raise), side bridge, modified push-up, squat, and standing shoulder flexion, on and off a labile surface.	RA, EO, ES (L4-L5)	% MVIC
Marshall & Desai (41)	N= 10 (20).	10 exercises: quadruped (quadruped opposite arm-leg raise), side bridge, modified push-up, squat, and standing shoulder flexion, with and without abdominal bracing.	RA, EO, ES (L4-L5)	% MVIC
Jung et al. (36)	N= 14 (14).	2 exercises: unstable supine bridging exercise, unstable prone bridging exercise (plank exercise).	IO, RA, MF, ICLT (L1)	% MVIC
Oh (45)	N= 20 (20).	2 exercises: prone hip extension with and without pelvic belt.	ES (L1), GM, BF	% MVIC
Kim et al. (38)	N= 20 (40).	2 exercises: prone hip extension with and without external pelvic compression.	LD, GM*, ES (L1)*, BF	% MVIC *****% Submax.

Yoon et al. (57)	N= 10 (10).	3 exercises: quadruped arm raise, quadruped leg raise, quadruped opposite arm-leg raise.	EO, IO, MF, ICLT	% MVIC
Kim et al. (39)	N= 12 (12).	2 exercises: supine bridging exercise with and without laser pointer.	ES (unknow level), GM, HAM	% MVIC

RA = rectus abdominis, EO = external oblique, IO = internal oblique, MF = lumbar multifidus, ES = erector spinae, ICLT = thoracic part of the iliocostalis lumborum, LD = latissimus dorsi, GM = gluteus maximus, BF = biceps femoris, HAM = hamstring. MVIC = maximum voluntary isometric contraction, *normalized with a submaximum voluntary isometric contraction.

Table 4. EMG activity.

Exercises	**Muscles**			
Arokoski et al. (4)	RA	EO	MF (L5)	
Ex.1 Walking on a trampoline	5-10%	35-40%	40-45%	
Ex.2 Leg swinging while standing	5-10%	25-30%	35-40%	
Ex.3 Weights in hands and altering shoulder flexion while standing straight	0-5%	20-25%	40-45%	
Ex.4 Weights in hands and altering shoulder flexion while standing straight on the balance board	0-5%	25-30%	55-60%	
Ex.8 Resisted upper-extremity extension while standing	50-55%	50-55%	5-10%	
Ex.9 Resisted upper-extremity flexion while standing	0-5%	20-25%	55-60%	
Ex.10 Resisted upper-extremity adduction while standing	5-10%	40-45%	30-35%	
Ex.5 Weights in hands and altering shoulder flexion while sitting straight	0-5%	20-25%	25-30%	
Ex.6 Backward and forward rocking in high sitting	0-5%	15-20%	20-25%	
Ex.7 Unilateral leg extension with upper body prone on the board	5-10%	20-25%	30-35%	
Ex.17 Resisted bilateral leg extension while prone	5-10%	15-20%	55-60%	
Ex.18 Bilateral leg extension while prone	5-10%	15-20%	70-75%	
Ex.11 Contralateral arm and leg lift in the all-fours position (quadruped opposite arm-leg raise)	5-10%	40-45%	40-45%	
Ex.15 Transversus abdominis exercise	5-10%	30-35%	5-10%	
Ex.13 Pushing bent knees against a soft ball in crook lying	5-10%	25-30%	20-25%	
Ex.12 Lifting hips up to a bridged position (conditions of instability)	0-5%	10-15%	60-65%	
Ex.14 Unilateral knee extension while keeping hips in a bridged position	5-10%	20-25%	65-70%	

(conditions of instability)				
Ex.16 Unilateral leg lift against resistance while lying on 1 side	5-10%	20-25%	15-20%	
Desai and Marshall (23)	RA	EO	ES (L4-L5)	
Quadruped (quadruped opposite arm-leg raise) Contralateral muscle/Ipsilateral muscle	10.0% ± 7.1 /11.1% ± 6.7	15.7% ± 10.5 /33.3% ± 20.2	23.6% ± 16.9 /18.5% ± 13.4	
Quadruped (quadruped opposite arm-leg raise) on unstable surface Contralateral muscle/Ipsilateral muscle	9.6% ± 7.3 /10.7% ± 8.0	20.7% ± 14.2 /51.9% ± 33.1	32.9% ± 30.8 /26.3% ± 19.0	
Side bridge Contralateral/Ipsilateral	19.2% ± 9.6 /55.0% ± 23.4	10.5% ± 4.7 /77.3% ± 27.6	15.7% ± 25.3 /38.6% ± 28.8	
Side bridge on labile surface Contralateral/Ipsilateral	16.7% ± 10.5 /46.9% ± 26.4	12.6% ± 5.5 /92.03% ± 41.8	19.9% ± 26.3 /65.7% ± 54.6	
Modified push-up	11.5% ± 8.1	16.9% ± 9.4	4.6% ± 2.1	
Modified push-up on labile surface	17.1% ± 22.4	23.7% ± 13.0	6.5% ± 6.1	
Squat	6.4% ± 3.3	8.1% ± 4.9	37.2% ± 9.4	
Squat on labile surface	6.4 ± 4.4	10.0 ± 5.2	29.6% ± 14.6	
Shoulder flexion	11.8% ± 5.6	14.7% ± 6.3	36.6% ± 19.3	
Shoulder flexion on labile surface	11.2% ± 6.0	21.3% ± 11.7	50.5% ± 37.1	
Marshall and Desai (41)	RA	EO	ES (L4-L5)	
Quadruped (quadruped opposite arm-leg raise) Contralateral muscle/Ipsilateral muscle	11.1% ± 1.9 /12.2% ± 1.8	22.6% ± 3.3 /52.2% ± 9.9	26.0% ± 3.6 /20.4% ± 2.9	
Quadruped (quadruped opposite arm-leg raise) with abdominal bracing Contralateral muscle/Ipsilateral muscle	16.5% ± 3.0 /15.6% ± 2.4	42.5% ± 7.9 /67.8% ± 9.2	38.8% ± 7.4 /32.5% ± 4.4	
Side bridge Contralateral/Ipsilateral	20.5% ± 2.3 /60.5% ± 6.8	15.2% ± 1.9 /108.9% ± 12.6	41.7% ± 6.3 /20.3%	

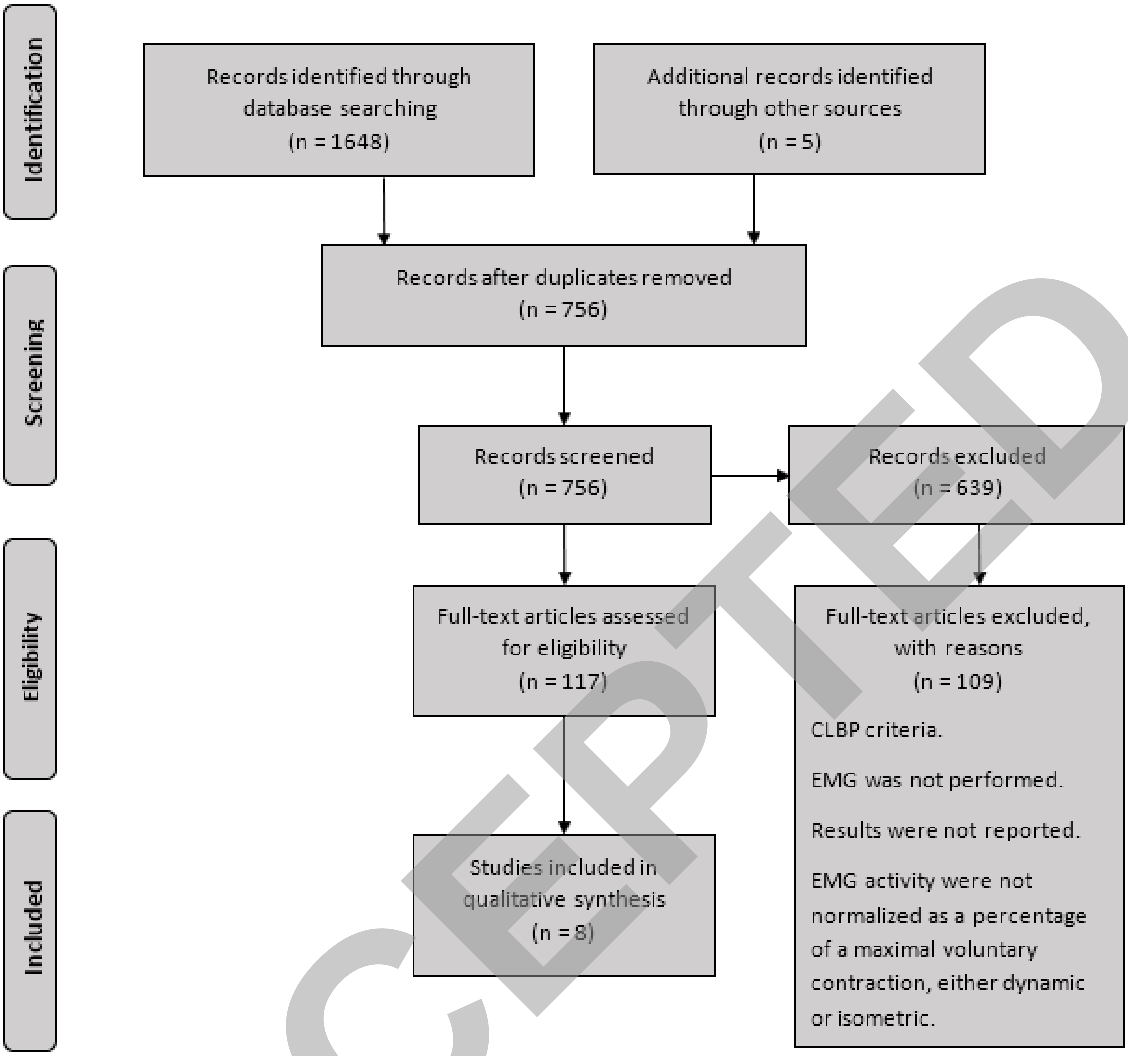
			± 8.3	
Side bridge with abdominal bracing Contralateral/Ipsilateral	24.0% ± 3.2 /57.1% ± 9.5	29.9% ± 4.0 /115.1% ± 13.4	27.0% ± 8.9 /63.2% ± 11.0	
Modified push-up	12.4% ± 2.6	24.0% ± 4.7	5.0% ± 0.7	
Modified push-up with abdominal bracing	33.8% ± 13.3	56.5% ± 8.9	11.1% ± 2.2	
Squat	6.8% ± 1.0	12.1% ± 2.9	42.3% ± 3.5	
Squat with abdominal bracing	10.4% ± 1.9	30.3% ± 4.1	52.8% ± 9.0	
Shoulder flexion	12.8% ± 1.9	19.9% ± 2.7	42.0% ± 8.4	
Shoulder flexion with abdominal bracing	15.1% ± 2.9	39.3% ± 3.2	56.9% ± 14.3	
Jung et al. (36)	RA	IO	MF	ICLT (L1)
Unstable supine bridging exercise	2.10% ± 1.54	9.81% ± 6.68	34.05% ± 11.64	25.23% ± 11.05
Unstable prone bridging exercise (unstable plank)	42.10% ± 18.59	30.10% ± 6.22	12.05% ± 11.02	11.16% ± 7.40
Oh (45)	ES (L1)	GM	BF	
Prone hip extension Left/right	49.87% ± 9.69 /47.41% ± 12.09	- /30.31% ± 14.22	-	
Prone hip extension with pelvic belt Left/right	39.79% ± 7.08 /40.16% ± 12.13	- / 24.18% ± 7.59	-	
Kim et al. (38)	ES (L1)*	BF	GM*	LD
Prone hip extension Left/right	51.87% ± 11.69 / 50.41% ± 18.12	5.21% ± 2.21 / 44.17% ± 20.41	15.97% ± 9.41 / 33.31% ± 16.65	13.62% ± 4.24 / 9.75% ± 4.21
Prone hip extension with external pelvic compression Left/right	41.79% ± 8.08 / 43.16% ± 14.13	9.87% ± 2.11 / 42.78% ± 16.97	15.13% ± 8.86 / 27.24% ± 10.59	10.77% ± 3.32 / 9.41% ± 4.55
Yoon et al. (57)	EO	IO	MF	ILCT
Quadruped arm raise Left/right	20-40% / 20-40%	0-20% / 0-20%	0-20% / 0-20%	20-40% / 0-20%
Quadruped leg raise Left/right	20-40% / 20-40%	0-20% / 0-20%	0-20% / 0-20%	20% / 20-40%
Quadruped opposite arm-leg raise	20-40% /	20% / 0-	20-40% /	40-60% /

Left/right	20-40%	20%	40-60%	20-40%
Kim et al. (39)	GM	ES	HAM	
Supine bridging exercise	21.3% ± 12.9	43.1% ± 16.8	41.7% ± 32.3	
Supine bridging exercise with laser pointer	28.6% ± 18.0	26.8% ± 15.1	53.3% ± 52.3	

RA = rectus abdominis, EO = external oblique, IO = internal oblique, MF = lumbar multifidus, ES = erector spinae, ICLT = thoracic part of the iliocostalis lumborum, LD = latissimus dorsi, GM = gluteus maximus, BF = biceps femoris, HAM = hamstring. *normalized with a maximum voluntary isometric contraction.

Table 5. Results of the applied methodological evaluation scale.

Authors, year	**Selection bias**	**Data collection**	**Report of the data**	**Results (modified EPHPP tool)**
Arokoski et al. (4)	Weak	Strong	Moderate	**Moderate**
Desai & Marshall (23)	Weak	Strong	Strong	**Moderate**
Marshall & Desai (41)	Weak	Strong	Strong	**Moderate**
Jung et al. (36)	Weak	Strong	Strong	**Moderate**
Oh (45)	Weak	Strong	Weak	**Weak**
Kim et al. (38)	Weak	Strong	Strong	**Moderate**
Yoon et al. (57)	Weak	Strong	Moderate	**Moderate**
Kim et al. (39)	Weak	Strong	Weak	**Weak**


Identification
Records identified through database searching (n = 1648)
Additional records identified through other sources (n = 5)
Screening
Records after duplicates removed (n = 756)
Records screened (n = 756)
Records excluded (n = 639)
Eligibility
Full-text articles assessed for eligibility (n = 117)
Full-text articles excluded, with reasons (n = 109)
CLBP criteria.
EMG was not performed.
Results were not reported.
EMG activity were not normalized as a percentage of a maximal voluntary contraction, either dynamic or isometric.
Included
Studies included in qualitative synthesis (n = 8)