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REVIEW PAPER

Validity and everyday clinical applicability of lumbar muscle fatigue assessment methods in patients with chronic non-specific low back pain: a systematic review

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ABSTRACT
Purpose: This systematic literature review aimed at examining the validity and applicability in everyday clinical rehabilitation practise of methods for the assessment of back muscle fatiguability in patients with chronic non-specific low back pain (CNSLBP). *Methods*: Extensive research was performed in MEDLINE, Cumulative Index of Nursing and Allied Health Literature (CINAHL), Embase, Physiotherapy Evidence Database (PEDro) and Cochrane Central Register of Controlled Trials (CENTRAL) databases from their inception to September 2014. Potentially relevant articles were also manually looked for in the reference lists of the identified publications. Studies examining lumbar muscle fatigue in people with CNSLBP were selected. Two reviewers independently selected the articles, carried out the study quality assessment and extracted the results. A modified Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) scale was used to evaluate the scientific rigour of the selected works. *Results*: Twenty-four studies fulfilled the selection criteria and were included in the systematic review. We found conflicting data regarding the validity of methods used to examine back muscle fatigue. The Biering-Sorensen test, performed in conjunction with surface electromyography spectral analysis, turned out to be the most widely used and comparatively, the most optimal modality currently available to assess objective back muscle fatigue in daily clinical practise, even though critical limitations are discussed. *Conclusions*: Future research should address the identification of an advanced method for lower back fatigue assessment in patients with CNSLBP which, eventually, might provide physical therapists with an objective and reliable test usable in everyday clinical practise.

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Electromyography, fatigue, low back pain, lumbar muscles

➤ IMPLICATIONS FOR REHABILITATION

- Despite its limitations, the Biering-Sorensen test is currently the most used, convenient and easily available fatiguing test for lumbar muscles.
- To increase validity and reliability of the Biering-Sorensen test, concomitant activation of synergistic muscles should be taken into account.
- Pooled mean frequency and half-width of the spectrum are currently the most valid electromyographic parameters to assess fatigue in chronic non-specific low back pain.
- Body mass index, grading of pain and level of disability of the study population should be reported to enhance research quality.

Introduction

Chronic non-specific low back pain (CNSLBP) is an increasingly common complaint which results in substantial disability. Non-specific low back pain is defined as low back pain not attributable to a recognisable or known specific pathology (e.g. infection, tumour, osteoporosis, fracture, structural deformity, inflammatory disorder, radicular syndrome or cauda equina syndrome).[1,2] It is therefore interpreted as a symptom, not a disease, and a lack of objective findings makes it difficult to determine the actual anatomical sources involved and the most targeted and effective management strategies.[2]

In the last three decades, CNSLBP has been suggested to be related to localised muscle fatigue and

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people with CNSLBP have been reported to exhibit earlier manifestation of fatigue (lower endurance) in back muscles than healthy people.[3–14] Many studies have increasingly addressed the association of excessive fatiguability and weakness of paraspinal muscles with CNSLBP. For this purpose, several fatiguing tests have been devised to induce back muscle fatigue and measure endurance. Still, to our knowledge, there is no clear evidence about which procedure is currently the most reliable and affordable as far as the many available methods proposed in literature are concerned. Indeed, some critical limitations for this kind of tests are the subject's motivation and other psychological aspects, such as fear of impending pain, as well as concomitant conditions that lead to effort intolerance, which can significantly affect the time of endurance. It has to be pointed out that ethnicity and gender might also significantly influence the outcomes of the tests.[15–20]

To overcome the aforementioned limitations, surface electromyography (sEMG) has been advocated as a tool for objective and non-invasive assessment of back muscle fatigue.[11,21–23] The evaluation of back extensor muscle fatiguability has increasingly gained importance for its implications when assessing patients with CNSLBP and lots of investigations have been conducted by means of endurance tests performed in conjunction with sEMG recordings. However, different strategies have been proposed to analyse sEMG signals and identify the best-suited parameters to track fatigue, leading to a wide variation among studies in terms of methodology, sEMG parameters and homogeneity of the study population.[24]

Overall, numerous combinations of different fatiguing procedures and diverse sEMG analyses have been reported in literature, generating uncertainty about which is the most reliable approach to assess lumbar muscle fatigue in CNSLBP patients. Furthermore, for a given assessment modality, it is crucial to consider whether the proposed method has been validated through research studies conducted in laboratories by means of complex, not affordable and time-consuming experimental setups/protocols which, ultimately, may not be easily incorporated into daily clinical practise.

As far as the aforementioned issues are concerned, the purpose of this systematic literature review was to examine the validity and applicability in everyday clinical practise (see later for detailed definitions) of physiotherapeutic methods aimed at providing a reliable assessment of muscle fatigue in patients with CNSLBP. The work attempts to identify which is currently the most optimal approach to attain reliable fatigue indices and therefore help clinicians in choosing among the numerous available options for assessing lower back muscle fatigue with the aid of sEMG.

Methods

Data sources and articles search

Our literature search aimed at identifying all the studies that have evaluated muscle fatigue in patients with low back pain. Two of the involved authors (M.P. and G.I.) independently identified studies by searching within the following literature databases: MEDLINE, Cumulative Index of Nursing and Allied Health Literature (CINAHL), Embase, Physiotherapy Evidence Database (PEDro) and Cochrane Central Register of Controlled Trials (CENTRAL). Literature search was performed by using the electronic databases from their inception to September 2014. The following three groups of terms were identified for the search: (1) low back pain, lumbar pain, lumbar trouble, lumbago, backache; (2) electromyography, EMG, sEMG, electromyographic, electromyogram and (3) fatigue, fatigability, endurance, effort. The search process was performed by using each term of group (1) combined with each term of group (2) or with each term of group (3): ''low back pain'' AND (electromyogr* OR EMG OR sEMG); ''low back pain'' AND (fatigue OR fatigability OR endurance OR effort); ''lumbar pain'' AND (electromyogr* OR EMG OR sEMG); ''lumbar pain'' AND (fatigue OR fatigability OR endurance OR effort), and so on. The reference list of each selected article was examined thoroughly to identify other potential articles that might fulfil the eligibility criteria. Forward research with Science Citation Index was also conducted to identify and examine all the articles included in the reference list of the selected articles.

Study selection

Several criteria were used to select the eligible studies. Articles were included if: the text was written in English; the study design was classified as case–control, clinical trial or cross-sectional study reporting CNSLBP patients as participants; participants were adults aged >18 years; lumbar muscle fatiguing tests were performed. Data collection should comprise also surface electromyographic measurements. Chronic low back pain was defined as back pain lasting more than three months.[2] Articles were excluded if: the study had an inappropriate design (e.g. survey or qualitative study); participants were diagnosed with specific low back pain (due for instance to scoliosis, surgery, symptomatic lumbar disc herniations); participants reported acute/subacute (duration <3 months) or recurrent low back pain; lumbar muscle endurance was not tested; sEMG evaluation was performed exclusively after treatment; studies were conducted with intramuscular EMG recordings, thus with poor applicability in everyday clinical practise; studies were reported in theses, dissertations or published as conference proceedings, since in these cases a formal peer review process could have not been predisposed.

Data extraction and quality assessment of the studies

The literature search, data extraction, and quality assessment procedures were performed by two independent operators (M.P. and G.I.). The titles and abstracts of the selected articles generated by the search strategy described above were first screened to eliminate irrelevant articles. The full text of each of the remaining articles was then reviewed to determine eligibility. Eventually, the scientific rigour of the eligible studies was assessed with a modified Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement (checklist for cohort, case–control and cross-sectional studies). Among the 22 items of the checklist, the items referring to the title, introduction and discussion (seven elements) were excluded as we aimed at focussing exclusively on the quality of methods and results of the studies. A modified version of the STROBE scale was used since a valid, reliable and universally accepted scale for the assessment of the methodological quality of physical therapy trials still needs to be developed.[25] It has to be pointed out that STROBE scale pays particular attention to statistical methods and to confounders which critically affect the quality and relevance of outcome data. Each item was scored a maximum of 1 point if full reporting criteria were met and 0 point if the criteria were not met (binary selection criteria), for a total possible score of 15 points. Afterwards, descriptive statistics of the STROBE scores belonging to the eligible studies was performed. The studies presenting a score above the median value were classified as high-quality studies and selected for the analysis and discussion of the research outcomes.

Data synthesis and analysis

Kappa statistics were used to assess agreement between the two raters on article selection.

For each selected article, the names of the authors, the study settings, the number of participants, the subject's positioning and type of fatiguing activity, data from the sEMG analysis, and the main outcomes were collected.

When a given testing modality (fatiguing test coupled with sEMG analysis) turned out to be able to track fatigue and distinguish CNSLBP patients from controls with statistical significance, we performed effect size analysis by using Cohen's d for independent groups. We adopted the formula used in MBESS package for the statistical computing software R.

When Standard Error (SE) was reported in the paper, we calculated Standard Deviation as SE$\times$ *n*, where *n* is the sample size.

Validity

The validity of a testing procedure was defined as the ability of the employed fatiguing test and sEMG parameter to discriminate between CNSLBP patients and controls. An assessment modality was defined as "valid" if sensitive to group differences with statistical significance. We further calculated the effect size for each of the valid testing protocols in order to strengthen the outcomes of the review.

Everyday clinical applicability of the fatiguing tests

The parameters adopted to define the level of applicability of the endurance tests in daily clinical practise were:

- Time of execution: the test should be performed as quickly as possible, with a maximum time of 20–25 min, being the typical duration of a standard physiotherapeutic session not exceeding 30 min; the total duration of the test was inferred from the information reported in the text of the selected papers;
- Cost: the test should require equipment as less expensive as possible (for instance by using tools usually available in the clinical settings with no extra-cost needed);
- Simplicity of setup and execution: setup and procedure should be as simple as possible and highly reproducible in clinical settings, avoiding particularly complex and bulky equipment. Patients as well should easily understand the procedure with no special need for preliminary familiarisation. To be noted, for instance, that strain gauges used to measure applied forces necessitate to be often calibrated to assure accurate force measurement.

Applicability in everyday clinical practise has been graded from 0 to 3: for each of the three considered parameters, 1 point has been assigned when requirements were met.

Results

The aforementioned search strategy yielded 547 articles. The papers were screened through reading of the titles and abstracts or full articles. The flow of information through the different phases of the systematic review is depicted by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [26] flow chart reported in Figure 1. This process resulted in a total of 24 studies that fulfilled the selection criteria and were therefore included in the systematic review (Table 1) and considered eligible for the quality assessment through the modified STROBE scale.

The level of inter-rater reliability on article screening through reading of the titles and abstracts was excellent according to Fleiss (1981) [27] (kappa = 0.88, 95% CI: 0.81–1.0), as was the article selection through reading the full text of each remaining article (kappa = 0.83, 95% CI: 0.81–1.0).

Scores obtained through the modified STROBE rating process from the 24 eligible studies are reported in Table 2. Score discrepancies were rare and any discrepancy was resolved by consensus. The distribution of the scores is reported in Figure 2: the median score of the 24 eligible studies resulted to be 9 with a full range of variation from 6 to 12 and an interquartile range (IQR) from 8 to 11. Ten studies were then classified as high-quality studies with reference to their score (≥10) and further selected for the analysis and discussion of the outcomes (i.e. the validity of the fatiguing tests and sEMG indices of fatigue as well as the applicability of the fatiguing protocols in everyday clinical practise). Among them, nine studies were case–control,[28–36] while one study did not discriminate between case and control groups.[37]

The main outcomes of the high-quality studies are reported hereafter.

Fatiguing tests

Several fatiguing tests were employed in the experimental protocols: horizontal unsupported trunk holding (Biering-Sorensen, BS),[28,31–34] back extension on a static dynamometer in upright position with knee flexed (UPPflex) [28,32] or knee extended (UPPext),[37] isometric lumbar extension by lifting in semicrounched position without pelvic stabilisation (LIFflex) [28] or with knee extended combined with pelvic stabilisation (LIFext),[35] isometric back extension on David Back Clinic rig (DBC),[36] trunk flexion/extension cycles on the roman chair (RC),[29] trunk flexion/extension cycles on Biodex dynamometer (Biodex).[30]

Among them, BS was the most widely used (five studies), while the other seven tests were homogeneously distributed, one per study.

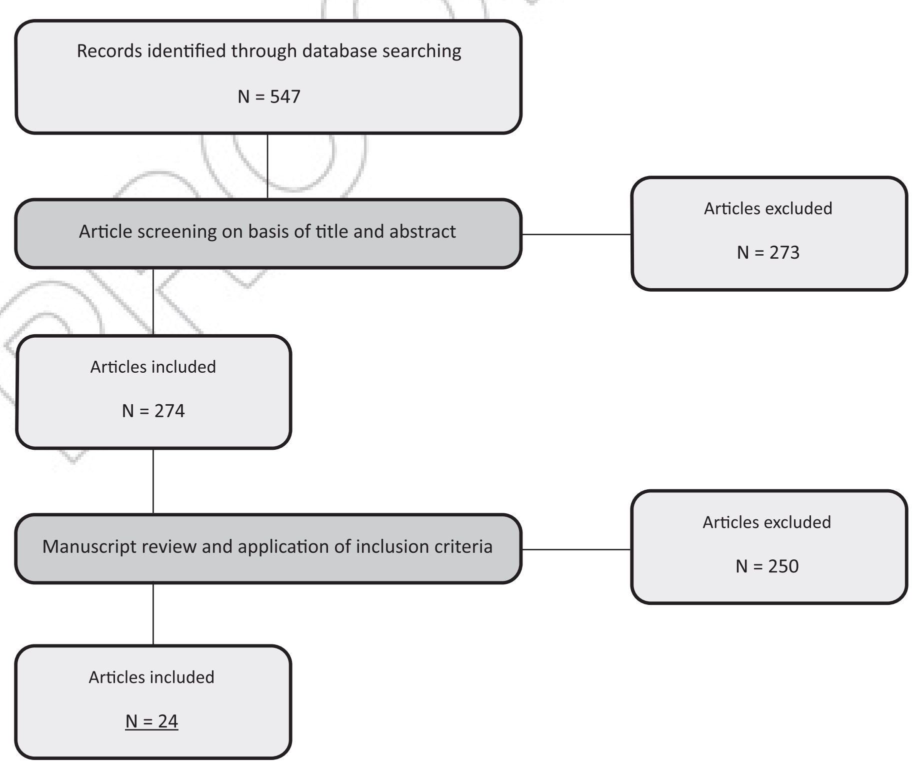

Figure 1. PRISMA flow diagram showing the process of paper selection. Twenty-four studies fulfilled the inclusion criteria concerning lumbar muscle fatigue assessment with the aid of surface electromyography in chronic non-specific low back pain.

Table 1. Characteristics of the included studies.

Study	Setting	Subjects	Position/activity measured	sEMG analysis	Findings
[9]	Laboratory	22 healthy subjects; 24 CNSLBP	Subject placed in a reference frame. Subject's posture non-properly described. Subjects had to hold a fixed load (11.6 pounds) with both arms stretched out in front of the body.	Median Frequency and RMS (pooled R/L and also absolute left/right difference). Electrodes were placed on multifidus (L4–L5) and on iliocostalis lumborum (L2–L3) bilaterally.	The scale 'Pain Behaviour Checklist' differentiated patients between 'avoiders' and 'confronters'. Avoider showed a fatigue rate of the multifidus that was twice as high as that of normal controls and confronters.
[38]	NS	30 subjects with chronic low back pain; 30 controls	Prone position, isometric fatigue test at 80% of MVC for 35 s, isometric post-fatigue test at 80% of MVC for 10 s.	Force and median frequency (slope coefficient alfa and beta, *y* and *y*1 intercept, the recovery index) from longissimus and iliocostalis lumborum muscles, bilaterally.	CNSLBP force lower than subjects without LBP. Variables (force, beta, *y*, *y*1, alfa) classify 89.5% of patients with pain and 84.0% of patients without pain. Variables (beta, *y*, *y*1, alfa, REC) classify 68.2% of patients with pain and 61.6% of patients without pain. Classification of Left longissimus muscle (variables: force, y, y1, REC) for patients with pain was 71.4%, for without pain was 66.7%. Significant differences between groups only on the left side.
[32]	NS	35 male patients with CNSLBP and 32 male control patients	Sorensen test and isometric trunk extension on back analysis system (BAS) at 60% of MVC.	Median frequency. Electrodes were positioned on paraspinal muscles (L4–L5).	MF decline during the Sorensen test was similar for controls and patients. MF decline was slightly but insignificantly greater in controls than in CNSLBP patients during the test on BAS.
[28]	A research laboratory within a rehabilitation centre	15 healthy controls, 13 subjects with CNSLBP	Static trunk extension during upright position test (UPP), semicrouched lifting test (LIF) and Sorensen test.	RMS and MF of surface EMG. Electrodes were positioned on longissimus (T10, L1), iliocostalis lumborum (L3) and on the multifidus (L5).	No significant between-group differences for the RMS and MF parameters on the three tests. The LIF test produced less fatigue than UPP and Sorensen tests.
[48]	NS	32 patients with CNSLBP, 39 controls	Standing extension test with pelvis fixed by a strap at 60% of MVC.	Computing of the slope of the median frequency (MF slope). Electrodes applied to lumbar trunk extensors bilaterally.	The investigated muscles resulted to be fatigued in all groups as MF slopes were negative. No comparison and statistical analysis were conducted to discriminate between groups.
[49]	Physiotherapy Clinic of the Rehabilitation School	20 patients with CNSLBP	Biering-Sorensen test.	Median frequency slope of iliocostalis and multifidus muscles were analysed.	Median frequency slopes were negative during the test. No statistical analysis was performed.
[39]	NS	55 controls, 57 CNSLBP	Seated isometric trunk extension on David Back Extension.	Median frequency during contractions at 80% of MVC. Electrodes were positioned on erector spinae (L1, L5 levels).	CNSLBP had higher initial median frequency at L5 compared to L1. Patients and healthy could be correctly classified in about 80% of the cases.
[35]	NS	174 normal, 145 CNSLBP, 30 past history	Isometric lumbar extension with knee extended and pelvic stabilisation.	EMG spectral variables: RMS, initial median frequency (IMF), peak amplitude, half-width, MF slope, MF mode during MVC for 30 s. Electrodes were positioned on erector spinae muscles (L4, L5).	Half-width, IMF and spectral peak amplitude demonstrated good discrimination between CNSLBP and normal subjects. MF slope and mode failed to distinguish normal subjects from CNSLBP.Overall, half-width was the most accurate discriminator and, in the multiple regression analysis, the only EMG-derived parameter that resulted to be an independent predictor of classification, being not correlated to MVC.
[33]	NS	16 CNSLBP, 16 control subjects	Sorensen test followed by six postural control trials on upright stance stable and unstable support surface.	Mean power frequency (MPF). Electrodes were placed on iliocostalis lumborum pars thoracis (L2) and MF muscles (L5).	CNSLBP showed shorter endurance time during Sorensen test. MPF of the back muscles declined significantly in both groups but there was no significant difference between groups.
[36]	Physical medicine and rehabilitation clinic in Finland	15 controls, 20 CNSLBP	Seated position on a David trainer (David Back Clinic rig). Isometric contraction at 50% of maximum voluntary contraction.	Median frequency (MF). Electrodes were attached over the lumbar paraspinal muscles (L3–L4, L5-S1) and on the Glutaeus maximus.	CNSLBP patients fatigued faster than controls.Glutaeus maximus MF slope showed steeper decrease in the CNSLBP than in the control group while no differences were observed in lumbar paraspinal muscle MF slope. There were no

(continued)

Table 1. Continued

Study	Setting	Subjects	Position/activity measured	sEMG analysis	Findings
					group differences in muscle loading.Pooled MF slope correlated strongly with endurance time, better than any individual muscle MF slope.
[40]	NS	14 controls, 15 CNSLBP	Subjects seated on a back extensor muscle training and measurement unit (DBC110) in which a fixation mechanism restricted the movement below L3.A submaximal isoinertial back endurance test, with repetitive flexion (25°)/extension (5°) cycles for 90 s, was conducted.	Mean power frequency slope (MPF); pooled MPF slope.	After rehabilitation, MPF slope significantly improved in ten CNSLBP patients. MPF slope validity was confirmed during the isoinertial back endurance test.
[37]	NS	20 controls; 20 patients with CNSLBP	Trunk extension on a static dynamometer in upright position with knee extended.	Indices of sEMG (MF slope, RMS slope, frequency band slope, area ratio index) at L5, L3, L1, T10.	RMS slope showed the more deficient reliability while MF slope was the most reliable index. Bilateral averaging was crucial to increase reliability. Averaging across all the investigated muscles was even better in increasing reliability.The averaging of measures across two fatigue tests increased the reliability by about 13%.
[41]	NS	40 volunteers (20 controls and 20 CNSLBP patients)	Healthy subjects (men and women) and chronic low back pain patients (men only) performed, in a static dynamometer, maximal and submaximal static trunk extension tasks (short and long duration) to assess weakness, fibre composition and fatigue.	Surface EMG signals were recorded from four (bilateral) pairs of back muscles and three pairs of abdominal muscles.	The EMG parameters used to quantify weakness and fibre composition were insensitive to low back status and gender. The EMG fatigue parameters did not detect differences between genders but, unexpectedly, healthy men showed higher fatigability than back pain patients.
[29]	NS	18 healthy volunteers,18 patients with CNSLBP	Roman Chair endurance exercise, flexion/extension of the trunk	Normalised RMS (NRMS) slope and normalised instantaneous MF (NIMF) slope of surface EMG on L4, L3, longissimus at L1 and T10, glutaeus maximus (GM) and biceps femoris (BF).	NIMF slope resulted to be more reliable than NRMS slope. In both groups there was clear evidence of muscle fatigue for GM and less evidence of fatigue for lower back muscles. Upper back muscles and BF were concurrently recruited but did not fatigued.Healthy subjects reached exhaustion significantly later than patients but the exercise did not prove to be adequate to specifically fatigue lower back muscles.
[30]	NS	16 controls, 18 CNSLBP patients	Subjects seated on a Biodex Dynamometer. The dynamic back endurance exercise consisted of extending the trunk from a forward flexion posture of 25° to a −15° extension posture, for a 40° total ROM. Each flexion-extension cycle lasted 4 s (2 s of flexion and 2 s of extension) paced with a metronome (60 bpm).	Normalised RMS (NRMS) slope and normalised instantaneous MF (NIMF) slope.	The number of cycles until exhaustion was equivalent in healthy controls and patients. Participants presented clear evidence of back muscle fatigue (significantly negative NIMF slope and positive NRMS slope) but no between-group difference was obtained in any EMG comparison.
[42]	NS	50 patients with CNSLBP	Sorensen endurance test	Median frequency. Electrodes were placed on erector spinae muscle (L4–L5, T12-L1) and were applied on internal oblique (IO) and transversus abdominis (TA).	Strong relationship between rate of myoelectric fatigue and the measures of flexion-relaxation (more positive rates of fatigue are associated with higher flexion-relaxation ratios). A negative relationship was identified between the rates of myoelectric fatigue and latency response measured from right TA/IO muscle.

(continued)

Table 1. Continued

Study	Setting	Subjects	Position/activity measured	sEMG analysis	Findings
[43]	NS	17 healthy subjects, 46 CNSLBP	Biering-Sorensen test	Median frequency. Electrodes were placed over the right or left biceps femoris, one to midway along a line connecting the fibular head with the ischial tuberosity, glutaeus maximus and paraspinal muscles.	Significant differences were found in the MF slopes of the healthy and CNSLBP erector spinae muscles. Significant differences were found in the glutaeus maximus muscle of healthy and LBP females.
[44]	Neuromuscular Research Centre, Boston University	10 controls, 8 CNSLBP	Standing, isometric muscle activity on Back Analysis System (BAS)	Median frequency and slope at various submaximal levels at L1, L2, L5.	Higher median frequency imbalances among patients (typically higher on the injured side).
[45]	NS	14 male CNSLBP, 20 healthy man	Isometric trunk extension at 40% and 80% of MVC on a Back Analysis System	Median frequency (MF) and root mean square (RMS). Electrodes were placed on longissimus thoraces (L1), iliocostales lumborum (L2), multifidus muscle (L5).	The mean slopes at the 40% MVC as well as the 80% were significantly more negative in the control group compared with the CNSLBP group, indicating higher levels of neuromuscular fatigue in the control group.
[34]	NS	12 CNSLBP patients, 12 controls	Sorensen back endurance test	Spectral mean power frequency (MPF): initial MPF (first 5 s), end MPF(last 5 s), MPF slopes and pooled MPF. Electrodes were placed on erector spinae (L3).	CNSLBP cases had significantly shorter endurance time as compared to age- and gender-matched controls. No significant differences in IMPF were found between groups. CNSLBP patients had significantly higher MPF slope (left and right side) and pooled MPF slope than healthy controls.The isometric endurance time negatively correlated with body mass index.
[46]	NS	18 controls, 21 CNSLBP	Semistanding position. Isometric back extensor contractions at 60% of maximum voluntary contraction at T9, L3 and L5.	Median power frequency measured bilaterally from T9, L3 and L5.	CNSLBP subjects tented to have higher initial median power frequency during fatiguing contractions, and less decay compared to controls at lower levels of the spine.
[7]	NS	12 controls, 12 CNSLBP	Standing, isometric muscle activity.	Initial median frequency and slope of median frequency during contractions at 40%, 60% and 80% of MVC at L1, L2 and L5.	Controls had higher initial median frequency than patients for all contractile levels at L1, and lower slope at 80% MVC for the L2 and L5 sites.
[47]	NS	16 controls, 25 golfers with CNSLBP.	Prone, isometric hold with torso unsupported: Biering-Sorensen test.	Median frequency (MF) and slope on erector spinae at T12 and L4-5 levels.	The decline in MF was steeper for the lumbar spine compared with the thoracic spine in both groups. Lower initial median frequency at L4-5 compared to T12 in CNSLBP subjects.
[31]	NS	20 CNSLBP, 20 healthy control subjects.	Prone position: Sorensen back endurance test.	Median Frequency: initial MF (IMF) and MF slope. Electrodes were placed on erector spinae muscle (L3).	Male CNSLBP had shorter endurance time compared to healthy subjects. No significant differences in IMF were observed between the CNSLBP patients and healthy female subjects. No significant differences in MF slope were found between the female and male CNSLBP, and between patients and healthy subjects.They further demonstrated that, in both groups, subjects with higher body mass index fatigued faster.

Table 2. Assessment of the methodological quality of the studies.

Study	Methods										Results					Score
	Study design	Setting	Participants	Variables	Data sources/ measurement	Bias	Study size	Quantitative variables	Statistical methods	Funding	Participants	Descriptive data	Outcome data	Main results	Other analysis	
[9]	1	0	0	1	1	1	0	1	1	0	1	0	1	0	1	9
[38]	1	0	0	0	1	1	0	1	1	0	1	0	1	0	0	7
[32]	1	0	1	1	1	0	0	1	1	1	1	1	1	1	0	11
[28]	1	1	1	1	1	1	0	1	1	0	1	1	1	1	0	12
[48]	1	0	1	1	1	0	0	1	0	1	1	0	0	0	1	8
[49]	1	1	0	1	1	0	0	1	0	0	1	1	1	0	1	9
[39]	1	0	0	0	1	0	0	1	0	1	1	1	1	0	1	8
[35]	1	0	1	1	1	0	0	1	1	0	1	1	1	1	1	11
[33]	1	0	1	1	1	1	0	1	1	1	1	1	1	0	0	11
[36]	1	1	1	1	1	1	0	1	1	0	1	1	1	1	0	12
[40]	1	0	0	0	1	0	0	1	0	1	1	1	1	1	0	8
[37]	1	0	1	1	0	1	0	1	1	1	1	1	1	1	0	11
[41]	1	0	0	0	0	1	0	1	0	1	1	0	1	0	1	7
[29]	1	0	1	1	1	1	0	1	1	1	1	1	1	1	0	12
[30]	1	0	0	1	1	1	0	1	1	1	1	1	1	1	0	11
[42]	1	0	0	0	0	1	0	1	0	0	1	1	1	0	0	6
[43]	1	0	1	0	1	1	0	1	0	1	1	1	1	0	0	9
[44]	1	1	0	0	1	1	0	1	0	0	1	1	0	0	0	7
[45]	1	0	0	0	1	1	0	1	0	1	1	1	1	0	0	8
[34]	1	0	1	1	0	1	0	1	1	0	1	1	1	1	0	10
[46]	1	1	0	0	0	1	0	1	0	0	1	1	1	0	1	8
[7]	1	0	0	1	1	1	0	1	0	0	1	1	1	0	1	9
[47]	1	0	1	0	1	1	0	1	0	0	1	1	1	0	0	8
[31]	1	0	1	1	1	1	0	1	1	1	1	1	1	1	0	12

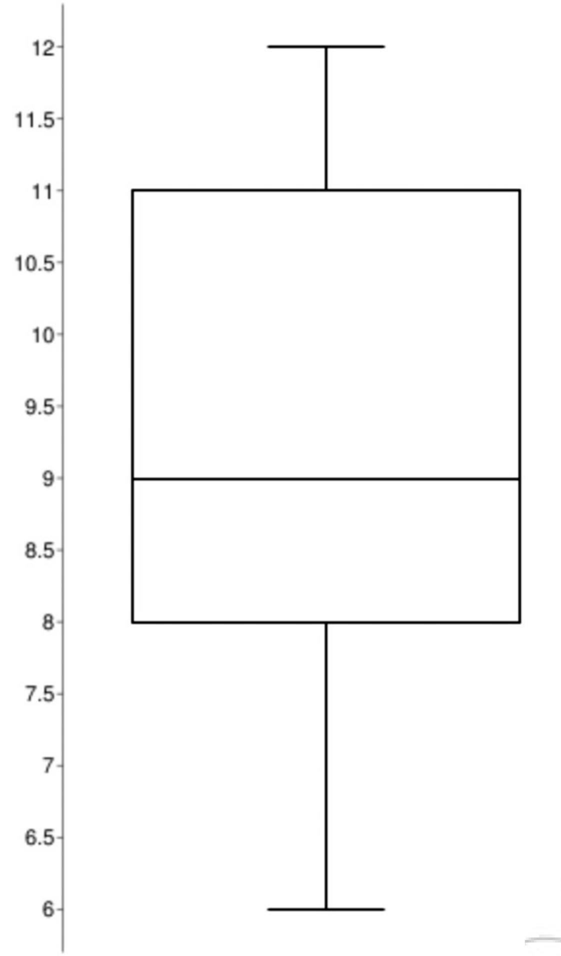

Figure 2. Box plot showing descriptive statistics of the modified STROBE scores belonging to the 24 eligible studies. Median score = 9; mean score (±SD) = 9.3 (±1.9); full range of variation = 6–12; interquartile range = 8–11.

Apart from RC and Biodex tests, which consisted of dynamic back endurance exercises, the tests were conducted in isometric conditions.

Da Silva et al. (2005) [28] compared three isometric tests and concluded that lack of control of lumbar lordosis during LIFflex may represent a limiting factor which may lead to less fatigue production with respect to BS and UPPflex.

Lariviere et al. (2010a) [29] provided evidence that adapted RC exercise, with hips flexed at 40°, is not well suited to specifically fatigue back muscles since hip extensors are concomitantly largely involved. Moreover, the authors pointed out that RC permitted more freedom to change the kinematics of the spine during the exercise, namely by allowing progressively less lumbar and more thoracic motion, thus contributing to delay lower back muscle fatigue by sharing the load between lower and upper back muscles.

As far as the duration of the fatiguing task is concerned, two main categories of tests can be distinguished: tests providing back-extension exertion until exhaustion (BS, DBC, RC, Biodex) and tests providing a fatiguing phase with fixed duration at a specific relative workload (% of the maximal voluntary contraction, %MVC) without necessarily reaching complete task failure (UPPflex, UPPext, LIFflex, LIFext). Among the absolute endurance tests, BS, DBC and RC proved to be valid in discriminating CNSLBP subjects with respect to healthy controls as a result of the significant differences in time to task failure (to be noted that sEMG is not taken into consideration here: as reported hereafter, for RC there was no significant difference in the sEMG parameters between groups). The Biodex test provided no significant differences in the number of repetitions. Nevertheless, the authors (Lariviere et al., 2010b) [30] reported some critical limitations in the study, namely sample size and group matching. None of the tests with fixed duration proved to be valid in discriminating patients from controls, except for LIFext.

Electromyographic analyses

The sEMG parameters used as fatigue indices were: median frequency (MF) slope,[28,31,32,35,36] mean power frequency (MPF) slope,[33,34] pooled MF slope,[36] root mean square (RMS) slope,[28,35] peak amplitude of the spectrum (peak amp),[35] spectral width at half peak amplitude (half-width),[35] modal frequency of the spectrum (modal freq),[35] normalised RMS slope (NRMS slope), and [29,30] normalised instantaneous MF slope (NIMF slope).[29,30] Some indices were expressed for single or muscle pairs (i.e. mean of the left and right homologous muscles), while others were averaged across a group of synergistic muscles recruited during the task. For the purpose of this review, "pooling" refers to calculation of the mean of grouped data, thus not referring merely to homologous bilateral muscles.

Surface EMG parameters other than the aforementioned myoelectric fatigue indices were used to attain complementary information aimed at providing an optimal interpretation of the results: initial median frequency (IMF) [35,36] calculated in the first seconds of the bout, average EMG amplitude (aEMG) [36] calculated in the first seconds of the bout and aEMG relative to the maximum aEMG amplitude in MVC contraction (aEMG%).[36]

Discussion

The main outcomes belonging to the selected high-quality studies are here discussed with the aim of identifying the most optimal way of assessing back muscle fatigue in CNSLBP subjects in daily clinical practise. In particular, the analysis of the results belonging to the eligible studies allowed us to investigate the validity in discriminating CNSLBP patients from controls and the applicability of the proposed methods in everyday clinical settings. Furthermore, we retrieved some additional relevant information and identified specific and general limitations of the studies, which allowed us to provide some perspectives and suggestions for future research.

The majority of the studies were conducted in isometric conditions and this seems in line with the fact that rhythmic intermittent contractions of the back muscles are not usual during everyday life. In other words, repetitive flexion-extension cycles seem to be less adherent to everyday trunk activity and consequently not well suited for proper back muscle fatigue assessment. Therefore, back muscle activities in isometric conditions are likely to be more appropriate to assess fatiguability even though activities of daily living are usually performed at lower workloads, namely 15–30% MVC, compared to the ones attained during the aforementioned endurance tests (40–70% MVC).

Concerning only the duration of the fatiguing task, a particular issue has to be considered. In this regard, two main categories of tests can be distinguished: tests providing back-extension exertion until exhaustion (to be more properly defined as "absolute endurance tests") and tests providing a fatiguing phase with fixed duration at a specific relative workload (% of the maximal voluntary contraction, %MVC) without reaching complete task failure. The latter require inevitably that MVC has been preliminarily determined to set the relative magnitude of the load. However, it is well known that subjects with CNSLBP are generally "avoiders" and therefore reluctant to exert actual maximal performances.[19] Consequently, the validity of this type of performance measures is questionable because of the detrimental influence of the psychological factors and the high risk of underestimating back muscle capacity.

Among the absolute endurance tests, BS, DBC and RC proved to be valid methods being BS the most widely used test. It is important to underline that validity of the fatiguing tests takes into account only endurance time, without considering sEMG analysis, and it is therefore subjected to many critical limitations as previously reported. Indeed, the validity of RC is not confirmed by sEMG parameters (see later in the text).

From the point of view of applicability, it was inferred that the investigated fatiguing tests are almost applicable and feasible in a standard physiotherapy session lasting 30 min. However, some setups and procedures are quite complex (sometimes custom-built and therefore poorly reproducible and accepted in clinical environments), time-consuming (especially for non-trained personnel) and require not commonly available devices and/or bulky rigs (extra-cost needed). This is particularly evident for the fatiguing tests performed at relative values of MVC since preliminary MVC measurements are needed, as well as dynamometers equipped with load-cells, visual feedback on computer screens and computers for real-time elaboration, thus implying extra-costs for the clinic. Altogether, these requirements make the tests based on MVC rather eligible only for laboratories engaged in advanced research studies and not perfectly suited for wide clinical application. Among all the fatiguing tests, BS featured the fastest execution in terms of setup and procedure (<10 min) and resulted to be the less expensive modality, serving therefore as an affordable clinical tool.

We further considered the combinations of the various fatiguing tests and sEMG parameters adopted in the nine high-quality studies conducted through case/control study designs. All the retrieved combinations are listed in Table 3. For each combination, validity in discriminating patients from controls and the level of applicability in everyday clinical practise are shown. For those protocols that resulted to be valid, effect size is also reported.

The following combinations were found to be valid: BS + MPF slope (effect size: 3.46); DBC + pooled MF slope (effect size: 0.51); LIFext + half-width (effect size: 0.99); LIFext + RMS slope (effect size: 0.64); LIFext + peak amp (effect size: 0.46); LIFext + modal freq (effect size: 0.19); LIFext + MF slope (effect size: 0.14).

Among them, the DBC and LIFext methods are actually not easy to transfer to clinical settings as they require devices that are not ordinarily available in usual practise. For LIFext in particular, limitations can also be due to time needed for set-up completion before proper test execution (at least 20 min) and to the fact that patients have to perform maximal contractions which can be largely affected by psychological avoidance.

On the other hand, BS represented the shortest test, rather inexpensive and showing no particular complexity. This test appeared particularly well-suited for clinical assessment even though some critical limitations exist. Indeed, severely compromised patients might not be able to sustain even efforts lasting few seconds, thus requiring a different approach. Furthermore, another limitation of BS is represented by BMI of the subjects, since tests in horizontal position may be particularly influenced by trunk weight.[17,31,34]

Concerning the fatigue indices, BS + MPF slope showed the highest effect size with respect to other combinations (Table 3), although, in general, this assessment modality resulted to have poor validity.

Table 3. Combinations of fatiguing tests and sEMG parameters used in the nine high-quality case–control studies.

Fatigue test	sEMG parameter	Validity	ES	Applicability	Reference
BS	MF slope	-		3	[31]
BS	MF slope (R/L)	-		3	[32]
BS	MF slope (R/L)	-		3	[28]
BS	MPF slope	-		3	[33]
BS	MPF slope (R/L)	+	3.46	3	[34]
BS	RMS slope	-		3	[28]
UPPflex	MF slope	-		1 [long, complex]	[32]
UPPflex	MF slope	-		1 [complex, costly]	[28]
UPPflex	RMS slope	-		1 [complex, costly]	[28]
LIFflex	MF slope	-		1 [complex, costly]	[28]
LIFflex	RMS slope	-		1 [complex, costly]	[28]
LIFext	MF slope (R/L)	+	0.14	1 [complex, costly]	[35]
LIFext	RMS slope (R/L)	+	0.64	1 [complex, costly]	[35]
LIFext	modal freq (R/L)	+	0.19	1 [complex, costly]	[35]
LIFext	peak amp (R/L)	+	0.46	1 [complex, costly]	[35]
LIFext	half-width (R/L)	+	0.99	1 [complex, costly]	[35]
DBC	MF slope	-		2 [complex, costly]	[36]
DBC	pooled MF slope	+	0.51	2 [complex, costly]	[36]
RC	NIMF slope (R/L)	-		3	[29]
RC	NRMS slope (R/L)	-		3	[29]
Biodex	NIMF slope (R/L)	-		2 [costly]	[30]
Biodex	NRMS slope (R/L)	-		2 [costly]	[30]

(R/L) indicates that the values of the investigated sEMG parameter were averaged bilaterally and expressed as mean of the right and left homologous muscles. Pooled parameters indicate that the values have been averaged across a group of agonist muscles and not merely left and right homologous muscles. Validity in discriminating CNSLBP patients from controls is reported (+ valid/− non valid). Effect size (ES) is reported for valid combinations. Applicability in everyday clinical practise has been graded from 1 to 3; the reasons leading to scores lower than 3 are reported in square brackets.

Indeed, despite the fact that BS + MPF slope was valid in many low-quality studies, only one [34] out of five high-quality studies attested the validity of this approach. Poor validity of BS + MPF slope is likely to be ascribed to a combination of inherent and methodological issues. Most importantly, for the purposes of using sEMG as a tool to track fatigue during BS test, MPF (or MF) analysis applied exclusively to paraspinal muscles (thus focussing only on local back extensor muscle fatigue) seems to be an unreliable method which can cause results misinterpretation. It is indeed crucial to consider that, during BS, synergistic muscles (glutaeal and hamstrings above all) are concomitantly engaged to varying extent in order to maintain trunk suspension, especially by individuals with low back pain.[36] For this, synergistic muscle activation may substantially delay the fatigue onset of low back muscles thus masking their actual endurance ability. In this line, pooling MF slopes (i.e. averaging across a group of coactive muscles that are recruited during the task: for instance paraspinal, glutaeal and hamstring muscles) has been advocated as a more reliable procedure able to comprise the contribution of multiple muscles, without omitting possible simultaneous involvement of synergistic muscles.[36] For this, a more general approach, characterised by a full picture of the fatigue phenomenon occurring in different coactive muscles during the endurance task, may represent an appropriate solution to overcome biases due to activation of muscles others than low paraspinal ones.[36] Future studies should address this issue and add more evidence regarding BS combined with pooled spectral analysis, which, for instance, proved to be valid when coupled with DBC.[36] As an alternative, BS validity could also be explored in combination with half-width calculation (i.e. the spectral width at half peak amplitude of the power spectrum), since this parameter provided the highest accuracy and effect size with respect to MF slope and other EMG parameters when coupled with LIFext in a large sample of CNSLBP patients (N =145; Humphrey et al., 2005).[35] As previously underlined, both DBC and LIFext present limitations in terms of applicability. In future perspectives, this implies that the evaluation of currently unexplored combinations employing accurate and valid sEMG parameters, such as pooled MF slope and spectral half-width, together with affordable fatiguing tests would be highly recommended for their potential routine application in clinical settings.

Normalization of fatigue indices with respect to initial values did not improve significance and therefore does not seem to be very useful. Conversely, repetition of the test with data averaging provided more reliability [37]: in this view, a submaximal fatiguing test with fixed duration could represent an optimal solution since the majority of CNSLBP patients do not reach complete task failure during a fixed (not exhausting) performance and, consequently, repetition of the test is likely to be feasible in the same physiotherapy session after adequate recovery.

Ultimately, on the basis of the outcomes of this review, we suggest severity of the chronic back pain condition to be carefully graded in future studies (with scales and questionnaires such as Von Korff's Chronic Pain Grade,[50] Visual Analogue Scale,[51,52] Numeric Pain Rating Scale,[53] Oswestry Disability Index,[54,55] Roland Morris Disability Questionnaire,[56] Fear-Avoidance Beliefs Questionnaire [57]) in order to choose the most appropriate evaluation approach and interpret the results at best. Indeed, patients could not be sufficiently impaired to show structural and functional changes or, on the other hand, excessive pain could determine earlier task failure not actually due to real muscle fatigue. Reporting the grading outcomes would substantially enhance the quality of the studies.

Conclusions

Surface EMG is an objective and non-invasive tool to evaluate lumbar muscle fatigue. Nevertheless, in our systematic literature review, we found inconsistent findings about the validity and reliability of the currently available methods aimed at discriminating between patients with CNSLBP and healthy controls based on fatigue assessment. The heterogeneity of the methodological approaches and results retrieved in the analysed papers provides limited evidence on the topic. Further high-quality studies are therefore needed to improve evidence regarding the existing modalities used to objectively assess lumbar muscle endurance, with the final aim of providing practitioners with the most valid and tailored approach to each different and peculiar CNSLBP population. In addition, future research should address the design of novel integrative methods (combination of advanced fatiguing tests and objective biological signal analyses) that could provide clinicians with affordable and reliable tests intended to be used in everyday clinical practise.

Declaration of interest

The authors report no conflict of interests.

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