A Meta-Analytic Review of Surface Electromyography Among Persons With Low Back Pain and Normal, Healthy Controls

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Abstract: **Significant differences in surface electromyography (SEMG) have been reported between persons with low back pain (LBP) and normal, healthy controls. This manuscript presents a systematic meta-analytic review of studies examining SEMG differences between these groups. Forty-four articles were identified using MEDLINE and a review of reference lists in articles. For static SEMG, the largest effect size was observed for SEMG while standing, with subjects having LBP demonstrating higher SEMG. The effect size for flexion/relaxation measures was found to be very high ($d = -1.71$). Studies examining SEMG during isometric exercise or muscle recovery following exercise produced inconsistent findings. Sensitivity and specificity of SEMG for dynamic SEMG measures averaged 88.8% and 81.3%. Most classification schemes were statistically determined and utilized a combination of measures. Only one published study prospectively validated a classification scheme. SEMG measures of flexion-relaxation appear to distinguish LBP subjects from controls with good accuracy, and the sensitivity and specificity of SEMG can be increased by using multiple measures. Further research is needed to determine the combination of measures that are cost-effective, reliable, valid and discriminate with a high degree of accuracy between healthy persons and those with LBP.**

Perspective: ***SEMG is a simple and noninvasive measure of muscle activity. SEMG measures hold promise as an objective marker of LBP.***

Key words: *Low back pain, surface electromyography, muscle, action potentials, chronic low back pain.*

Many persons with low back pain (LBP) lack objective pathology. In addition, objective indicators of pathology detected by tests such as magnetic resonance imaging (MRI) are not specific to persons with LBP, as these abnormalities are present in many asymptomatic individuals.[7,32,72] Although musculoskeletal dysfunctions have been identified as a cause of LBP,[25,63] there is little evidence that these dysfunctions can be assessed reliably.[25] In addition, contemporary models of chronic low back pain (CLBP) should also attend to psychosocial factors that might influence the experience of pain.[22,23]

Models of CLBP have been proposed that focus on biomechanical and musculoskeletal factors in the etiology and maintenance of back pain.[12,15,18,26,44,49,53,71] Studies testing these models often employ surface electromyography (SEMG) to measure muscle action potentials. A growing literature suggests that there are significant differences in SEMG activity between persons with and without LBP, and that SEMG measures can accurately differentiate these persons. These findings suggest that SEMG may serve as an objective marker of LBP.

Despite the fact that SEMG assessment is simple and noninvasive, concerns have been raised about its use in LBP populations. Two previous reviews suggested that SEMG has little utility in diagnosing and treating back pain, as the technique is deemed to be inferior to other methods such as needle electromyography (EMG).[27,57] In addition, SEMG is prone to measurement artifacts such as impedance produced by the skin.[19] Some recommend "normalizing" SEMG signals to a reference measurement taken from the same individual to reduce these artifacts. However, reference measurements in such studies often involve assessing SEMG during maximal effort. Persons with LBP often have difficulty putting forth maximal effort

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during such tasks, which likely biases the values obtained.[43]

Further complicating SEMG assessment is the infinite number of conditions under which SEMG can be obtained. SEMG can be collected during static postures or dynamic movements, from different sites on the back, and from each side of the back. Some authors suggest that SEMG asymmetries in muscles on opposite sides of the back are highly characteristic of LBP.[73] To date, there has been little study of the types of SEMG measurements or experimental conditions that maximize the differences observed between subjects with LBP and healthy controls. Further research is needed to determine whether there are SEMG measurements and methods that consistently produce large differences between these groups.

The use of SEMG as an objective measure of back pain has potential advantages. Given that the majority of subjects with LBP lack measurable pathology (eg, neurologic deficit) SEMG could serve as a method of objectively measuring and monitoring the condition. Second, there is some suggestion that SEMG is sensitive to spinal pathology associated with LBP and changes that occur with remediation of the problem. For example, Haig et al[28] observed an abnormal flexion-relaxation response in a patient with an acute disk herniation, which resolved over time as the patient's pain resolved. Third, SEMG measures have been shown to be influenced by psychosocial factors believed to contribute to back pain, such as fear of movement and reinjury and psychological stress.[14,21,24,71] Thus, SEMG may be sensitive to both physical and psychosocial influences, and reflect important parameters that are consistent with a biopsychosocial model of pain.[61]

This manuscript presents a systematic review and meta-analysis of the published literature on SEMG differences between persons with and without LBP. We wished to determine the effect sizes associated with specific SEMG measures as well as their sensitivity and specificity. Based on the findings, we sought to provide recommendations regarding whether SEMG measures can serve as objective measures of LBP.

Materials and Methods

Data Sources

Studies were identified utilizing MEDLINE. Reference sections from identified studies were used as an additional source of studies.

Study Selection

Surface electromyography, SEMG, EMG, and back pain were used as keywords in MEDLINE. Articles which examined SEMG only in LBP populations, or only in normals, were excluded. Two articles that met the above criteria were excluded as they did not study subjects with LBP.[20,47] This search identified 44 articles on SEMG and LBP.

Definitions of LBP vary greatly from study to study. Most commonly, studies examined subjects with CLBP (duration greater than 3 or 6 months). Often, the etiology of back pain was unspecified, and only a few studies examined SEMG in specific diagnostic groups of persons with LBP. CLBP was typically defined as long-lasting pain with no evidence of metastatic disease, neurologic compromise, or other spinal abnormalities. Subjects in these studies were often characterized as having CLBP due to musculoskeletal or idiopathic causes.

Data Extraction

A qualitative review of studies is provided in the Results section. In addition, a meta-analysis was performed to examine the effect sizes associated with various SEMG measures. Reported sensitivity and specificity was also analyzed. Effect sizes for each study (standardized mean difference, *d*) were computed by subtracting the mean of the normal group from the mean of the LBP group, and dividing by the pooled standard deviation.[13] A positive effect size indicates that LBP subjects had higher SEMG than normals, whereas a negative effect size denotes that normals had higher SEMG than LBP subjects. Ten studies[10,11,12,20,35,37,46,50,52,56] were excluded from the calculation of effect sizes as these studies did not report the necessary means and standard deviations. Data from manuscripts reporting data graphically were extrapolated. Sensitivities and specificities were extracted as reported. A summary of the studies reviewed are presented in Tables 1 and 2. Table 1 presents the studies included in the meta-analysis, while Table 2 presents the remaining studies.

Prior to computing effect sizes, data from some studies were averaged. To maintain consistency, the means and standard deviations from studies reporting SEMG separately for each side of the back were averaged prior to determining the effect size. The exception was for studies where the authors reported SEMG activity separately for the active and inactive side of the back during unilateral activity. In addition, some studies reported data separately for different levels of SEMG measurement (eg, L1 and L2), while others reported averages across levels. Again, to maintain consistency, effect sizes for each level of measurement were averaged. Studies reporting side-to-side differences in SEMG, or differences based on the area of assessment, will be outlined qualitatively in the review.

Given that the methodologies and conditions for studying SEMG varied greatly across studies, it was deemed that the effect sizes from all studies could not be summarized as a whole in a meaningful way. For presentation, the effect sizes are grouped as follows: (1) SEMG during a static position; (2) SEMG during a dynamic activity, such as bending; (3) SEMG during an isometric hold, contraction, or exertion; and (4) SEMG response to an expected or unexpected increase in physical demand, or following the release of a physical demand.

The effect sizes reported are not entirely independent. If a study reported SEMG differences between diagnostic groups, the comparison between each patient group and the normal healthy control group were computed as separate effect sizes. However, the data for the control

Table 1. Summary of Studies Examined in Meta-analysis

Study	Subjects	Position/Activity Measured	Type SEMG	Findings	Sensitivity/Specificity	Variables Used
Ahern et al, 1988[1]	40 controls, 40 CLBP (>6 mos)	Standing, flexion/extension, rotation	Raw SEMG L3–4 and L4–5	Standing no difference. Controls higher SEMG in flexion, extension, and rotation, and higher flexion/extension and rotation indices	84.6%/87.5%	Range of motion, flexion index, mean level in flexion
Alexiev, 1994[2]	40 controls, 40 acute (<1 month) LBP	Standing, isometric muscle activity	Integrated SEMG during contractions of 30%, 50%, and 100% of MVC recorded at L3	Higher SEMG on painful side in CLBP subjects, no SEMG group differences	No	
Ambroz et al, 2000[3]	30 controls 30 CLBP (>6 mos)	Standing, flexion/extension	Raw SEMG averaged from T11–L5	CLBP higher while standing, higher flexion/extension ratio	No	
Arena et al, 1989[4]	29 controls, 19 spondyloarthritis, 52 disk disorders, 66 musculoskeletal, 17 combined, 24 other (duration criteria unspecified)	Standing, bending, rising, unsupported sitting, supported sitting, and prone	Raw lumbar SEMG	Standing: controls lower SEMG. Sitting supported: disk disorders higher SEMG. Rising: controls and spondyloarthritis lower SEMG. Bending: Controls lower SEMG except spondyloarthritis, spondyloarthritis lower SEMG than disk disorder and CLBP	Standing 50% spondyloarthritis, 48.1% disk disorders, 45.5% musculoskeletal, 76.5% combined, 39.1% other/93.1% Sitting supported 15% spondyloarthritis, 32.7% disk disorders, 15.2% musculoskeletal, 0% combined, 8.7% other/93.1%	SEMG in each position
Arena et al, 1990*[5]	20 controls, 29 mixed LBP (duration criteria unspecified)	Standing, bending, rising, unsupported sitting, supported sitting, and prone during two testing sessions	Raw lumbar SEMG	SEMG less stable over time in subjects with CLBP. Overall ANOVA revealed no group differences	No	
Arena et al, 1991[6]	20 controls, 21 disk disorders, 25 musculoskeletal (duration criteria unspecified)	Standing, bending, rising, unsupported sitting, supported sitting, and prone. Back pain subjects were tested while having high and low pain	Raw lumbar SEMG	Nonsignificant trend for all subjects to have higher SEMG during second (high pain) testing. Controls lower SEMG when standing, and disk disorder subjects higher SEMG when sitting supported	Abnormal SEMG in any position, high and low pain combined: 61.9% disk disorders, 56% musculoskeletal/80%	EMG in each position
Capadaglio and Nilsson, 1996†[8]	4 control, 4 CLBP (duration criteria unspecified)	Isometric contraction at 60% of MVC voluntary level	Initial median frequency at L4	Higher initial: median frequency for controls	No	
Cassisi et al, 1993[9]	12 controls, 21 CLBP (>6 mos)	Sitting, maximal isometric exertion at different angles of flexion	Integrated SEMG L1–2	CLBP had lower SEMG at all angles of flexion and at rest	86%/83%	Maximum SEMG at 48° and 0°

Table 1. Continued...

Study	Subjects	Position/Activity Measured	Type SEMG	Findings	Sensitivity/Specificity	Variables Used
DeGood et al, 1994[17]	12 controls, 10 disabling chronic low back or neck pain, 10 nondisabling low back or neck pain (duration criteria unspecified)	Mental stress while sitting	SEMG change from baseline at cervical or lumbar level	Disabling back pain subjects displayed highest SEMG, controls the lowest	No	
Elfving et al, 2003[20]	55 controls, 57 CLBP (>12 months)	Seated isometric trunk extension	Median frequency during contractions at 80% of MVC	CLBP had higher initial median frequency at L5 compared to L1	86%/78%	Combination of strength and SEMG variables
Jalovaara et al, 1995‡[31]	11 controls, 10 disc hemiation, 15 radiating pain, 18 LBP (duration criteria unspecified)	Standing	Raw SEMG at T10, L2, and L5	Patients with CLBP higher SEMG at L5 and L2	No	
Kankaanpää et al, 1998[33]	15 controls, 20 CLBP (>3 mos)	Isometric contraction at 50% of maximum voluntary contraction	Median frequency at L3–4, L5-S1, and gluteus over time	No difference in initial median frequency. Gluteal fatigue slower in normals compared to other sites and gluteal muscles of CLBP patients	No	
Klein et al, 1991§[34]	17 controls, 8 LBP (duration criteria unspecified)	Isometric contraction at 80% of maximum voluntary contraction for 10 seconds	Median frequency over time at L1, L2, L5	SEMG differences not reported	1 min after contraction: 88%/100% 2 min after contraction: 100%/80%	1 min after contraction: right recovery L5, left slope L2, right slope L5, left recovery L2, right slope L2, left initial median frequency L5 2 mins after contraction: right recovery L5, right slope L2, right slope L5, right recovery L1, left slope L2, left recovery L5
Lee et al, 1992‖[38]	10 controls, 8 mechanical CLBP (duration criteria unspecified)	Prone, isometric holds with torso unsupported	Integrated lumbar SEMG	No statistical comparison done	No	
Leinonen et al, 2001[39]	15 controls, 20 disk herniation patients with CLBP (duration criteria unspecified)	Expected and unexpected loading of the upper extremities while sitting and standing	Reflex latency and duration from T12–L1 and L5–S1	Response latency shortened by expectation in controls while standing, but not in patients. No group differences in reflex duration	No	

Table 1. Continued...

Study	Subjects	Position/Activity Measured	Type SEMG	Findings	Sensitivity/Specificity	Variables Used
Lisiński, 2000¶[40]	31 controls, 62 subjects with CLBP (duration criteria unspecified)	Prone, isometric hold for 2 seconds with torso unsupported	Mean SEMG amplitude, density, background density, upper amplitude, and upper density at T7 and L4	Controls significantly higher on all measures except background density, background amplitude, and upper density at T7, and upper density at L4	No	
Lofland et al, 2000[41]	30 controls, 18 CLBP patients with high symptom excess, 33 CLBP patients with low symptom excess (duration criteria unspecified)	Standing	Raw SEMG L1–L4	SEMG higher in high symptom excess group compare to controls and low symptom excess group	Discriminant analysis done to classify patients only	
Lu et al, 2001[42]	20 controls, 20 CLBP (>6 mos)	Standing in postural restraint device, performing lifts with and without trunk rotation	Percent of maximum isometric contraction during symmetrical task, and correlations between left and right side during symmetrical tasks recorded over lumbar region	Patients had higher SEMG and greater unbalanced SEMG activity between the right and left side while performing a symmetric lift	No	
Mayer et al, 1989[43]	11 controls, 10 CLBP (duration criteria unspecified)	Prone, isometric hold for 15 seconds with torso unsupported. Two 10-consecutive-trial sessions	Initial mean power frequency slope for first and last 5 trials of first session	Steeper slopes (lower endurance) among patients compared to normals	40%/100%	Mean power frequency slope
Miller, 1985[45]	11 controls, 11 CLBP (>6 months)	Sitting, standing, active sitting	Integrated SEMG at L3–4 and L4–5 normalized to SEMG in flexion	No differences between patients and controls	No	
Ng et al, 2002#[51]	12 controls, 12 CLBP (>12 months)	Axial rotation while standing at different levels of effort	Raw SEMG from rectus abdominis, external and internal obliques, latissimus dorsi, iliocostalis lumborum, multifidus	Higher activity in patients in external obliques, and lower activity in multifidus during left axial rotation During right rotation, patients had lower activity in rectus abdominus at higher exertion levels	No	
Pääsuke et al, 2002[54]	12 controls, 12 CLBP (>3 mos)	Prone, isometric hold with torso unsupported	Mean power frequency at L3	CLBP subjects displayed greater fatigue	No	

Table 1. Continued...

Study	Subjects	Position/Activity Measured	Type SEMG	Findings	Sensitivity/Specificity	Variables Used
Peach and McGill, 1998[55]	18 controls, 21 CLBP (>6 mos)	Semistanding	Isometric back extensor contractions at 60% of maximum voluntary contraction at T9, L3, and L5	CLBP subjects tended to have higher initial median power frequency during fatiguing contractions, and less decay compared to controls at lower levels of the spine	93.8%/100%	Change in initial median power frequency, initial median power frequency during contraction, initial median power frequency during repeat contraction, and median power frequency decay during fatigue and repeat contraction
Radebold et al, 2000[58]	17 controls, 17 CLBP (>6 mos)	Standing, supported with feet off the ground	Muscle recovery time in response to quick release test at 12 different sites	Patients displayed slower reaction times in agonist and antagonist muscles. Patients also maintained agonist muscle contractions while activating antagonistic muscles	No	
Radebold et al, 2001[59]	14 controls, 16 CLBP (>6 mos)	Standing, supported with feet off the ground	Muscle recovery time in response to quick release test at 12 different sites	Patients displayed slower reaction times in agonist and antagonist muscles	No	
Robinson et al, 1992[60]	12 controls, 16 CLBP (duration criteria unspecified)	Sitting, repetitive concentric and eccentric contractions with light and heavy resistance	Integrated SEMG fatigue curves at L1–L2	CLBP had lower muscle activity during exercise. Controls had negative slope fatigue curve, while CLBP had slightly positive curve	No	
Roy et al, 1989[64]	12 controls, 12 CLBP (>12 mos)	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 slopes at 80% MVC for the L2 and L5 sites	For 40% MVC: 82%/92% For 60%MVC: 75%/67% For 80% MVC: 91%/84%	Combination of slope and initial median frequency values at different recording sites
Roy et al, 1990[65]	23 rowers, 6 with low back pain (duration criteria unspecified)	Standing, isometric muscle activity	Initial median frequency, slope, and recovery of median frequency at 1 minute following contraction at 80% of MVC at L1, L2, and L5	Overall, recovery at 5 sites and slope at L1 significantly discriminated between rowers with and without back pain	100%/93%	Recovery bilaterally at L1 and L5, left side recovery at L2, and left slope recorded from L1

Table 1. Continued...

Study	Subjects	Position/Activity Measured	Type SEMG	Findings	Sensitivity/Specificity	Variables Used
Roy et al, 1995[66]	Sample 1: 42 controls, 28 CLBP; Sample 26 controls, 57 CLBP (duration criteria unspecified)	Standing, isometric muscle activity	Initial median frequency, slope and recovery following contraction at 80% of MVC recorded at L1, L2–3, and L5	Initial median frequency and slope from 6 recording sited from sample 1 entered stepwise to create discriminant function, which then was applied to sample 2	Sample 1: 85%/86% Sample 2: 88%/100%	Median frequency and slope from L1, median frequency from all 3 sites on the left
Shirado et al, 1995[67]	25 controls, 20 CLBP (>6 mos)	Flexion and extension	Ratio of SEMG during activity to SEMG while standing	No difference in SEMG during flexion, CLBP lower SEMG from full flexion to standing	No	
Sihvonen et al, 1991[68]	25 controls, 87 CLBP (duration criteria unspecified)	Flexion and extension	Intramuscular and rectified surface SEMG at L4 and L5	Lower decrease in flexion in patients, and a lower extension/flexion ratio	No	
Sihvonen et al, 1998[69]	21 healthy, pregnant women and 32 pregnant women with back pain with onset before pregnancy	Flexion and extension	Averaged SEMG at L4–5	Higher SEMG in flexion among back pain subjects, and lower activity during back motion	No	
Suter and Lindsay, 2001[70]	16 controls, 25 golfers with CLBP (>6 mos)	Prone, isometric hold with torso unsupported	Median frequency and slope at T12 and L4–5	Lower initial median frequency at L4–5 in CLBP subjects	No	
Watson et al, 1997[71]	20 controls, 70 CLBP (>6 mos)	Flexion and extension	Raw SEMG at L1–2 and L4–5	Patients had significantly lower SEMG at L4–5 during flexion, higher SEMG in full flexion, lower SEMG during re-extension, and a lower flexion-relaxation ratio	93%/75%	Flexion relaxation ratios at both recording sites

Abbreviation: MVC, maximum voluntary contraction.

*This study examined SEMG in subjects with back pain and controls on 2 testing sessions to examine the temporal stability of SEMG in each group. Only the data from the first session was used in the meta-analysis.

†This study also examined SEMG fatigue slopes, but did not report group standard deviations. Therefore, only initial median frequency values were analyzed.

‡Means and standard deviations presented only for data at L5.

§Means and standard deviations not presented for SEMG data. Only results of discriminant analysis were used.

‖This study examined both acoustic myography and SEMG. Only SEMG data were used.

¶To have the data be comparable to other studies, only data from mean amplitude were included.

#SEMG was examined at a number of different effort levels. Only SEMG at maximum effort was included.

Table 2. Summary of Studies Reviewed but not Included in Meta-analysis

Study	Subjects	Position/Activity Measured	Type SEMG	Findings	Sensitivity/Specificity
Chen et al, 1998[10]	40 controls, 47 CLBP (>6 mos)	Static holding task in a neutral and flexed position	Integrated SEMG from rectus abdominis, external obliques, erector spinae, and latissimus dorsi	CLBP produced less SEMG during static tasks, and fewer changes in muscle co-activation	No
Chiou et al, 1999[11]	40 controls, 47 LBP (pain duration unspecified)	Static holding task in a neutral and flexed position	Integrated SEMG from rectus abdominis, external obliques, erector spinae, and latissimus dorsi	Different SEMG patterns across tasks between normals and CLBP subjects	No
Collins et al, 1982[14]	11 controls, 11 CLBP (>6 mos)	Standing, 45° bend, 90° bend, forward pelvic tilt, backward pelvic tilt, unsupported sitting, supine knees bent, mental arithmetic, cold-pressor test	Raw SEMG at L3 and L5	Trend for controls to have higher SEMG during more exertive postures	No
Hubley-Kozey and Vezina, 2002[30]	24 control, 14 CLBP (>7 wks)	Supine abdominal hollowing maneuver and leg-lifting tasks	Principal components analysis of muscle movement patterns recorded from 7 muscles	Three patterns identified. Patterns not different among muscle sites for controls, but different for patients	No
Kramer et al, 2001[35]	32 controls, 32 patients status-post transitory dorsal spondylodesis for vertebral fracture (>6 mos)	Prone, isometric holds with torso unsupported	Raw SEMG from iliocostal, longissimus, and multifidus	Patients had lower amplitudes in multifidus, and higher SEMG in iliocostal muscle	No
Leach et al, 1993[37]	6 controls, 10 acute LBP (<2 wks)	Standing, full flexion, full extension	Raw SEMG at T10 and L3, flexion/relaxation response, thoraco-lumbar asymmetry	Loss of flexion/relaxation in LBP subjects. Greater thoraco-lumbar asymmetry and right-left differences in patients	No
Mooney et al, 1997[46]	8 controls, 8 CLBP (average of 4 mos)	Seated isometric trunk extension	Mean power frequency and amplitude change at L3–4 and L4–5 as a function of an 8-week exercise program	Patients demonstrated less SEMG fatigue and work at the end of treatment compared to the start of treatment	No
Newcorner et al, 2002[50]	20 controls, 21 CLBP (>6 mos)	Muscle activation patterns during footplate perturbations	Latency of firing, frequency, and asymmetry of muscle activation at erector spinae, rectus abdominus, anterior tibialis, and gastronucleus	In toes-up movements, patients less likely to activate rectus abdominus, and more likely to have asymmetric muscle activation in small forward movements	No
Oddsson et al, 1997[52]	10 controls, 8 CLBP (pain duration unspecified)	Standing, isometric muscle activity	Median frequency and slope at various submaximal levels at L1, L2, L5	Higher median frequency imbalances among patients (typically higher on the injured side)	No
Pope et al, 2000[50]	11 normals, 11 CLBP (pain duration unspecified)	Standing, isometric muscle activity during sudden load	Transformed SEMG at L3 into discreet and continuous wavelets	Wavelet transformation more accurately measures reaction time compared to original signal	No

Table 3. Effect Sizes for Studies Examining EMG in Static Postures

Posture	Number of Effect Sizes	Mean Effect Size (SD)	Range	Mean Weighted Effect Size (SD)	Mean Sensitivity (Range)	Mean Specificity (Range)
All postures	63	.67 (.7)	−.20 to 4.81	.65 (.7)	39.6 (0 to 76.5)	90.8 (80 to 93.1)
Standing	20	1.14 (1.1)	−.03 to 4.81	1.11 (1.0)	53.6 (39.1 to 76.5)	89.5 (80 to 93.1)
Unsupported sitting	10	.44 (.1)	.26 to .71	.43 (.1)	NA	NA
Supported sitting	13	.35 (.3)	−.20 to .75	.34 (.3)	14.3 (0 to 32.7)	93.1
Sitting supported mental stress	10	.53 (.3)	.10 to .99	.52 (.3)	NA	NA
Prone	10	.50 (.2)	.23 to .69	.50 (.2)	NA	NA

Abbreviation: NA, not available.

group in these cases were the same. In addition, separate effect sizes were calculated for the same groups of subjects who underwent one or more conditions in an experiment. As treating nonindependent effects as independent can lead to errors in statistical tests of significance for effect sizes,[62] the effect sizes presented here are summarized qualitatively based on the guidelines put forth by Cohen.[13] Cohen defines an effect size of .2 as a small effect size, .5 a moderate effect size, and .8 a large effect size. To control for effect sizes based on a small number of subjects, a weighted effect size was also calculated which corrects for sample size based on the formula $d = J(m)g$, where g is the uncorrected effect size and $J(m) = 1 - (3/(4 \times df) - 1)$.[29,36] As one goes through the tables, however, there appears to be little difference between the actual and adjusted effect sizes. Therefore, the actual effect sizes are discussed and interpreted in the text, whereas the adjusted effect sizes are also presented in the tables.

Results

SEMG in a Static Position

A total of 63 effect sizes were extracted from 10 studies reporting static SEMG differences between LBP subjects and normals.[1,3,4,5,6,17,31,41,45,71] The effect sizes for the four static postures examined in these studies are presented in Table 3. In addition, 1 study examined SEMG in a sitting posture while undergoing various mental stressors.[17] The largest effect size was obtained for standing (n = 20, $d = 1.14$). The effect sizes for lying prone (n = 10, $d = .50$) and sitting supported while undergoing mental stress (n = 10, $d = .53$) were moderate. The effect sizes for unsupported (n = 10, $d = .44$) and supported sitting (n = 13, $d = .35$) were small to moderate.

Two studies[1,71] reported no significant SEMG differences between LBP subjects and normals while standing, and another study reported no group differences between LBP subjects and controls in 6 different postures, including standing.[5] Ahern et al[1] examined a measure of SEMG asymmetry between the right and left sides of the back while standing, and found no difference between LBP subjects and controls. Miller[45] observed no SEMG differences between LBP subjects and controls during quiet or active sitting (performing a task using the upper extremities), or while standing. This study examined SEMG that was normalized to SEMG levels in flexion. Five studies[3,4,6,30,38] reported that LBP subjects had higher SEMG levels during static postures compared to controls. Lofland et al[41] however, reported that this was only true for a subgroup of LBP subjects who displayed excessive and/or anatomically inconsistent motor, sensory and tenderness responses during a neurological examination. Jalavaara et al[31] found that subjects with idiopathic CLBP had higher SEMG than levels controls, whereas subjects with disc herniation and sciatica did not. DeGood et al[17] reported that subjects with disabling back pain (either upper or lower) had the highest SEMG levels compared to controls while sitting supported. Also, persons with disabling back pain displayed the greatest change in SEMG compared to baseline when performing mental arithmetic.

The effect sizes for sitting supported, unsupported, and lying prone primarily come from 3 studies conducted by Arena and colleagues.[4-6] In 1 study,[5] no overall group differences were observed. These authors also reported in two studies[4,6] that disk disorder subjects had higher SEMG than normals and other LBP patients when sitting supported. No group differences were observed when SEMG was measured when subjects were lying prone or sitting unsupported.

Findings from other studies from which effect sizes could not be calculated are also summarized here. Chen et al[10] found that LBP subjects had lower SEMG during static postures, and Chiou et al[11] observed that LBP subjects had different patterns of muscle activity than controls in various postures. Collins et al[14] studied LBP subjects and controls in static postures, with some postures that require exertion to maintain the posture (such as a 45° bend). The authors found that LBP patients had higher SEMG during most postures, particularly those that required exertion to maintain them.

Reported sensitivity and specificity from studies examining static SEMG measures are also reported in Table 3. These data come from 2 studies by Arena et al.[4,6] The authors reported that static SEMG has good specificity (ability to identify normal, healthy subjects), but poor sensitivity (ability to identify persons with LBP). The average sensitivity for all static postures combined was 39.6%, and the average specificity was 90.8%.

Table 4. Effect Sizes for Studies Examining Dynamic EMG

Activity	Number of Effect Sizes	Mean Effect Size (SD)	Range	Mean Weighted Effect Size (SD)	Mean Sensitivity (Range)	Mean Specificity (Range)
All activities	35	−.04 (0.8)	−2.10 to 1.26	−.04 (.8)	88.8 (84.6 to 93)	81.3 (75 to 987.5)
Rising	10	.25 (.3)	−.18 to .71	.24 (.3)	NA	NA
Active sitting—active side	1	.05	NA	.05	NA	NA
Active sitting—inactive side	1	.21	NA	.20	NA	NA
Flexion	14	.34 (.5)	−.79 to .79	.34 (.4)	NA	NA
Full flexion	1	1.26	NA	1.25	NA	NA
Reextension	3	−1.15 (.9)	−2.21 to −.60	−1.14 (.9)	NA	NA
Flexion-relaxation ratio*	4	−1.71 (.3)	−2.25 to −1.36	−1.70 (.3)	88.8 (84.6 to 93)	81.3 (75 to 87.5)
Rotation	3	−.63 (.4)	−.89 to −.18	−.62 (.4)	NA	NA

Abbreviation: NA, not available.

*The sensitivity and specificity listed for the flexion-relaxation ratio (FRR) is based on a combination of measures. In one study, it was the FRR from multiple recording sites, and in another it was combined with range-of-motion and mean EMG in flexion.

Dynamic SEMG

For dynamic activity, 37 effect sizes were calculated from 11 studies.[1,3,4,5,6,45,51,67,68,69,71] One study[45] examined SEMG during a unilateral upper extremity task, and reported SEMG separately for the side of the back ipsilateral to the active extremity (active), as well as the contralateral side (inactive side). The effect sizes are summarized in Table 4. The effect size obtained for active sitting-active side is small (n = 1, d = .05). The effect sizes for rising (n = 10, d = .25), active sitting-inactive side (n = 1, d = .21) and flexion (n = 14, d = .34) are all small to moderate. The effect size for trunk rotation (n = 3, d = −.63) was moderate to large. Large effect sizes were observed for re-extension following full flexion (n = 3, d = −1.15), and from 1 study examining SEMG in full flexion (d = 1.26).[67] Four studies examined flexion/relaxation differences between LBP differences and controls,[1,3,68,71] and the average effect size from these studies was very large (d = −1.71). This effect size is based on a total of 227 subjects with LBP and 115 control subjects. It is typically observed in SEMG studies that patients with LBP display an absence of paraspinal muscle relaxation in terminal flexion. This phenomenon, which is commonly observed in normal, healthy persons, is termed the flexion relaxation response. These four studies calculated a flexion-relaxation ratio (FRR) and compared LBP subjects to controls on this measure. The ratio typically involves a comparison of SEMG during flexion to SEMG in full flexion, with a smaller ratio denoting less paraspinal muscle relaxation in terminal flexion. Assuming that the distribution of FRR scores is normal in BP and healthy populations, the amount of nonoverlap between the distribution of scores between normals and LBP subjects is approximately 76% based on the average effect size observed in these studies.

Miller[45] reported no observed differences between LBP subjects and controls during active sitting on either the active or inactive side. Arena et al[4] reported that LBP subjects tended to have higher SEMG while bending and rising, although SEMG activity differed by LBP diagnosis. Sihvonen et al[69] also reported higher SEMG among LBP subjects during flexion, whereas Watson et al[71] and Ahern et al[1] reported lower SEMG among LBP subjects while in flexion. Shirado et al[67] reported no difference in SEMG among subjects with CLBP and controls during flexion, but lower EMG activity among subjects with CLBP during reextension. All studies that examined a FRR[1,3,68,71] reported a significantly lower ratio among LBP subjects compared to controls. Ahern et al[1] reported significant differences in right/left paraspinal activity between LBP patients and controls during rotation, and Ng et al[51] reported both higher and lower muscle activity among LBP subjects depending on the muscles examined and the direction of movement. Among studies not included in the meta-analysis, Hubley-Kozey and Vezina[30] reported that LBP subjects had different patterns of muscle activation during a supine hollowing abdominal maneuver and leg-lifting. Leach et al[37] reported that LBP patients had greater muscle asymmetry while bending and demonstrated a loss of flexion/relaxation.

Sensitivity and specificity for dynamic SEMG were reported in 2 studies. Watson et al[71] used FRRs from different recording sites to classify subjects, while Ahern et al[1] combined the FRR with lumbar range of motion, and SEMG in flexion. The average sensitivity from these 2 studies was 88.8%, and the mean specificity was 83.1%. These data are based on 110 subjects with LBP and 60 controls.

SEMG During Isometric Activity

A total of 22 effect sizes were examined from 14 studies.[2,8,9,20,30,33,38,42,43,54,55,60,64,70] In addition, 3 studies only examined the sensitivity and specificity of various SEMG measures.[34,65,66] These findings are presented in Table 5. Three studies examined integrated SEMG during isometric tasks.[2,9,38] The average effect size based on these 3 studies

Table 5. Effect Sizes for Studies EMG During Isometric Exertion

Activity	Number of Effect Sizes	Mean Effect Size (SD)	Range	Mean Weighted Effect Size (SD)	Mean Sensitivity (Range)	Mean Specificity (Range)
Overall	22	−.57 (1.1)	−2.35 to 2.21	−.55 (1.1)	84.4 (40 to 9100)	89.8 (67 to 9100)
Integrated	7	−1.28 (.6)	−1.85 to −.33	−1.24 (.6)	NA	NA
Initial median frequency	4	−.51 (.2)	−.72 to −.31	−.49 (.2)	NA	NA
Median frequency or mean power slope	8	0 (1.0)	−1.65 to 1.32	0 (1.0)	40 (NA)	100 (NA)
Mean amplitude	1	−2.34	NA	−2.33	NA	NA
Peak linear envelope	1	2.21	NA	2.17	NA	NA
Left-right correlation	1	−1.38	NA	−1.35	NA	NA

Abbreviation: NA, not available.

was large (n = 7, $d = -1.28$). The effect sizes for initial median frequency were all negative, and the combined average effect size was of moderate size (n = 4, $d = -.51$). Capadaglio and Nilsson,[8] Roy et al[64] and Suter and Lindsay[70] reported higher initial median frequency means in control subjects compared to LBP patients, while Kankaapää et al[33] found no difference between LBP patients and controls on this measure. It should be noted that effect sizes for initial median frequency could not be extracted from 2 studies that reported higher levels in LBP patients compared to controls.[20,55]

Eight effect sizes for median frequency or mean power decay over time were available from 7 studies. The mean effect size obtained was small (0). Five studies[33,43,54,64,70] found that LBP patients displayed greater decrease in SEMG over time, suggesting faster muscle fatigue (ie, greater muscle weakness) in this population. Two studies found evidence for slower decay over time in BP patients.[55,60] In normal control subjects, Peach and McGill[55] found greater decay in measurements taken from the lower portion of the back (L5) compared to measures taken a higher levels (L3 and T9). Subjects with back pain had equivalent decay at all levels. The authors suggested that in normal subjects the lower lumbar paraspinal muscles assume a greater workload during an isometric task, while in LBP subjects the load appears to be more evenly distributed. Robinson et al[60] found that CLBP subjects displayed less decay over time compared to controls and even found some evidence for greater muscle recruitment over time. These authors suggest that this may reflect the performance of deconditioned muscles or insincere task effort among LBP subjects.

Lisinski[40] examined several unique SEMG measures among LBP patients and controls during an isometric hold of the upper torso. The SEMG measures corresponded to various parameters (eg, number of fibers, firing frequency) of small and large motor units. The author found that mean amplitude, mean density, and upper amplitude were significantly higher among controls compared to BP subjects at the T7 level. At L4, the author reported higher levels in controls on these same measures, in addition to background amplitude and background density. The effect sizes reported were quite large (eg, −2.34).

Lu et al[42] compared normalized SEMG to SEMG during maximum voluntary contraction on a lifting task at 30% of maximum voluntary effort. The authors found significantly greater unbalanced (left side compared to right) muscle activity while lifting and higher average peak linear envelope SEMG (as a percent of maximum voluntary contraction) among LBP patients compared to controls. In addition, over the course of treatment, this observed asymmetry in muscle activity persisted despite increases in strength. The authors suggest that lack of muscle symmetry may help to explain the high rates of relapse among persons with CLBP. The effect size for the difference in right and left side correlations between the muscles of BP subjects and controls was very large ($d = -1.38$), as was the difference in the average peak linear envelope SEMG ($d = 2.21$).

For studies where effect sizes could not be computed, Kramer et al[35] found that LBP subjects had lower SEMG in the multifidus muscles and higher SEMG in the iliocostal muscles during a prone, isometric hold of the torso. Mooney et al[46] reported that CLBP subjects displayed less SEMG fatigue and work at the end of a rehabilitation program compared to the start. Oddsson et al[52] found that subjects with LBP displayed greater median frequency imbalances (with the injured side being higher compared to the uninjured side) during standing, isometric muscle contractions.

Sensitivity and specificity of isometric SEMG measures are presented in Table 5. All studies except for one[43] utilized a combination of SEMG measures to classify subjects (as determined by discriminant function analysis). Overall, the average sensitivity and specificity from studies utilizing these measures are high (84.4% and 89.8%, respectively). Only 1 study of all the studies reviewed attempted to replicate the classification scheme obtained in 1 sample in a second, independent sample. In this study, Roy et al[66] found that the classification scheme obtain from 1 subject sample had 88% sensitivity and 100% specificity in a second sample.

EMG Response to Initiation or Cessation of an Expected or Unexpected Physical Demand

Three studies fell into this category. All effect sizes obtained were small to moderate, with the exception of

Table 6. EMG Response to Expected or Unexpected Physical Demand or Release of Physical Demand

Activity	Number of Effect Sizes	Mean Effect Size (SD)	Range	Mean Weighted Effect Size (SD)
All activities	20	.37 (.4)	−.45 to 1.10	.36 (.4)
Recovery from load release — on antagonists	6	.66 (.3)	.30 to 1.10	.64 (.3)
Recovery from load release — off agonists	6	.46 (.2)	.20 to .69	.45 (.2)
Unexpected loading — reflex duration	2	.17 (.3)	−.04 to .37	.16 (.3)
Expected loading — reflex duration flexion	2	.13 (.2)	.02 to .24	.13 (.2)
Unexpected loading — latency	2	0 (.7)	−.45 to .51	0 (.7)
Expected loading — latency	2	−.02 (.2)	−.19 to .14	−.02 (.2)

a moderate to large (d = .66) effect size observed for slower antagonistic muscle recovery in LBP patients. These data are presented in Table 6. Radebold et al[58,59] found that persons with LBP displayed slower reaction times in agonist and antagonist muscles during the sudden release of a load while standing. LBP subjects also maintained agonist muscle contractions while activating antagonistic muscles.[58] Leinonen et al[39] found that muscle response latency was shortened by expectation in control subjects while standing, but not in persons with LBP. No group differences in reflex duration were observed.

In another study where effect sizes could not be determined, Pope et al[56] found that wavelet transformation of SEMG more accurately measured reaction time compared to the original signal during sudden release of a load.

Discussion

Some studies examining static SEMG found higher levels in persons with LBP compared to healthy subjects, while others reported no difference. The largest effect size was observed for standing, and greater differences were observed among persons with LBP who were disabled[17] or who displayed excessive pain behavior.[41] The effect sizes observed for dynamic SEMG measures tended to be larger compared to static measures, however, the results were more discrepant. Studies examining SEMG while rising or during flexion produced mixed results. One study reported greater SEMG among subjects with LBP in full flexion, and the effect size was very large (d = 1.26). Four studies consistently found a lower FRR among subjects with LBP, and the effect size observed was very large. Combining the FRR with other SEMG measures, or range of motion, produced good sensitivity (88.8%) and specificity (81.3%).

Consistent findings were observed in studies looking at integrated or initial median frequency SEMG during isometric exertion, as all found lower levels in persons with LBP. The effect size for integrated SEMG was very large, while effect sizes for median frequency shift or slope in the SEMG signal were mixed. One study examined unique SEMG measures during an isometric hold of the upper torso, such as mean amplitude of the SEMG signal, and reported very large effect sizes.[40] Another reported very large left and right SEMG asymmetries.[42] These findings appear to merit further study. Reported sensitivity and specificity of median power frequency slope combined with other measures was high (84.4% and 89.8%, respectively). Studies examining SEMG response to the initiation or termination of a physical demand produced small to moderate effect sizes.

Based on the findings, at least 2 factors appear to influence the results of studies examining SEMG and LBP. One factor is whether LBP is acute or chronic. CLBP is a complex disorder that is influenced by a number of different physical and psychosocial factors that also likely to influence SEMG. For example, subjects with CLBP are more likely to be deconditioned, as these subjects tend to avoid activities that are believed to cause pain.[16] Subject selection or sample factors should be considered when interpreting findings related to SEMG and LBP.

Second, CLBP populations are highly heterogeneous, and the types of samples studied likely influenced the findings. For example, Roy et al[65] utilized college rowers who did and did not report back pain, while Robinson et al[60] examined subjects with CLBP who were involved in a spine treatment and rehabilitation program and were presumably more disabled. These sample differences may account for both high and low levels of SEMG fatigue being observed among subjects with CLBP through sample differences in level of effort exerted during testing. For example, it is frequently observed that LBP patient populations typically perform poorer on strength tasks.[9] While this may reflect weakness, it may also reflect insincere effort due to pain or other factors.[42,71] This is important as normalizing SEMG to a maximal contraction is subject to the influence of subject effort.

Given that some SEMG measures are influenced by subject effort, it would be preferable to select a measure that is least subject to bias by effort. A standardized task may reduce bias due to subject effort. For example, in the present review, studies examining SEMG decay during an isometric hold of the torso all found greater decay among persons with LBP. However, a strenuous standardized task might be difficult for most LBP subjects to perform. For this reason, it would be preferable to select a task such as bending that most persons with LBP can

perform. Future research should consider assessing SEMG during nonstrenuous standardized tasks.

Given that insincere effort is common in some LBP populations, one might also consider choosing a SEMG method for which insincere effort, due to pain or other factors, biases the SEMG measure in a direction that is characteristic of a person with LBP. As examples, insincere effort on a measure of SEMG fatigue might bias the results in a way that makes a LBP subject look "stronger" like a normal healthy subject. Lack of effort (inability to bend) during a flexion-relaxation task potentially biases the SEMG measure to look like that of a person with LBP. However, if one were using SEMG in a medical-legal context, choosing the latter type of measurement makes it possible for a subject to "feign" having LBP through insincere effort. Further research is needed to determine the extent to which SEMG measures are influenced by factors such as sincerity of effort. This review suggests that SEMG evaluation methods that do not rely on assessment of maximal effort are less subject to bias.

It has been suggested that normalizing the SEMG signal is desirable, as factors that influence SEMG such as obesity[23] may systematically differ between persons with LBP and normal, healthy controls. Although normalizing SEMG to maximal effort may be problematic, other methods of normalizing SEMG data have been reported in the literature. For example, 2 studies normalized dynamic SEMG readings relative to SEMG while standing.[23,36] Such normalization potentially controls for between subject differences in certain SEMG artifacts but not differences in strength. However, it reduces bias as this normalization does not involve an assessment of maximal effort. Further research is needed to determine whether such normalization helps to reduce artifact and improves the reliability and validity of SEMG assessment.

Interpreting the findings as a whole, one measure that appears to produce consistent and strong group differences in SEMG between persons with LBP and controls is flexion-relaxation. This measure can be obtained on almost all persons with LBP, and insincere effort biases the SEMG reading toward being characteristic of a person with LBP. Overall, the average effect size was −1.71, and 4 studies consistently found a lower FRR among persons with LBP compared to controls. While this review suggests that a FRR alone can accurately discriminate 76% of persons with and without LBP, the studies reviewed indicate that sensitivity and specificity can be improved with additional measures. One additional measure that should be added to this assessment is lumbar range of motion. This is useful as it has been suggested that paraspinal relaxation only occurs once a person reaches about 40° of flexion.[1] In addition, limited range of motion is often present among persons with LBP,[63] and Ahern et al[1] found that this measure increased the predictive value of flexion-relaxation assessment. The optimal combination of measures that produces high sensitivity and specificity, while being practical for the clinician to obtain, remains to be determined. In addition, there is a need to prospectively evaluate the accuracy of any classification scheme in independent samples.

There is also evidence that the FRR is sensitive to clinical changes in LBP. The case study reported by Haig et al[28] suggests that the FRR changes over time in parallel with the clinical status of the patient. Watson et al[71] found that decreases in pain-related fear and increases in pain self-efficacy beliefs over the course of treatment were significantly associated with increases in the FRR, while changes in pain, disability, and range of movement were unrelated. Neblett et al[48] reported that the FRR of back pain subjects improved over the course of treatment, and that these improvements were associated with increases in range-of-motion and function. These studies support the use of the FRR as an objective marker of change in clinical status.

It should be noted that one potential shortcoming of this review is that subgrouping studies may have lead to statistical calculations based on small samples. This did not appear to be the case for the measures of effect size as the weighed measures that corrected for sample size differed little from the unweighted values. However, small sample sizes are also a concern when examining the calculation of average sensitivities and specificities, particularly because fewer studies reported these data.

In summary, this review suggests that certain SEMG measures have the potential to serve as objective markers of LBP. Two prior reviews concluded that SEMG was not a useful tool in the diagnosis and treatment of various neuromuscular diseases.[27,57] The current review suggests that there is evidence indicating that SEMG has utility in distinguishing between persons with LBP and controls in a blinded fashion, similar to what Pullman et al[57] refer to as "Class I" evidence. SEMG may have good utility as a marker for LBP because persons with the disorder typically do not display evidence of nerve or muscle damage. One measure that appears to hold promise as a marker of LBP based on the current review is the FRR. Further research is needed to determine the combination of measures that accurately identify LBP, and whether these measures are cost-effective and simple to obtain in clinical settings. Research is also needed to determine what factors contribute to SEMG abnormalities in LBP, and whether remediation of these factors predicts positive treatment outcomes.

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