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Trunk and Hip Surface Electromyographic Activity During Maximal Voluntary Isometric Contraction in Adults with Chronic Nonspecific Low Back Pain: A Cross-Sectional Study

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ABSTRACT: Chronic nonspecific low back pain (CNSLBP) may be associated with altered trunk and hip muscle activation, although surface electromyographic (sEMG) findings remain heterogeneous across muscles and testing conditions. This cross-sectional study compared bilateral trunk and hip sEMG activity during maximal voluntary isometric contraction (MVIC) between adults with CNSLBP and asymptomatic controls. Forty adults (20 CNSLBP and 20 controls) underwent standardized bilateral sEMG recording of the erector spinae, rectus abdominis, gluteus maximus, and gluteus medius. Participant-level bilateral work average (WAV), work average deviation (WAVDEV), and peak amplitude were analyzed. Non-normally distributed outcomes were compared using exact Mann–Whitney U tests with Hodges–Lehmann location-shift estimates and Holm correction for multiple comparisons. In unadjusted analyses, erector spinae WAV was lower in the CNSLBP group than in controls (51.75 [41.63–88.88] vs 75.50 [66.50–107.50] μV; p=0.026), as was rectus abdominis WAV (60.50 [42.25–86.00] vs 81.25 [60.25–135.63] μV; p=0.040). Erector spinae WAVDEV (p=0.010) and peak amplitude (p=0.043) were also nominally lower, whereas no between-group differences were observed for gluteal WAV. However, none of the comparisons remained statistically significant after Holm correction. Adults with CNSLBP therefore demonstrated nominally lower trunk sEMG activity during MVIC, particularly in the erector spinae and rectus abdominis, but the findings should be interpreted as exploratory rather than as evidence of a generalized or muscle-specific neuromuscular deficit.

1. INTRODUCTION

Low back pain remains the leading global cause of years lived with disability, affecting approximately 619 million people in 2020 and projected to reach 843 million by 2050 [1]. Its underlying mechanisms frequently overlap, and identification of a single anatomical pain generator is often difficult in nonspecific presentations [2]. Chronic low back pain is also associated with heterogeneous alterations in back-muscle function [3].

Neuromuscular activity in chronic low back pain is not uniformly reduced. During a modified Biering–Sorensen task, individuals with continuous chronic low back pain demonstrated greater erector spinae and multifidus surface electromyographic (sEMG) activity than healthy controls during concentric and holding phases [4]. Men with chronic nonspecific low back pain have also shown greater internal and external oblique activation while maintaining dynamic loads [5]. Muscle-synergy analyses further suggest task-dependent neuromuscular reorganization, whereby the overall structure of trunk synergies may remain preserved despite altered variability within specific synergies [6].

Hip-muscle function may also be affected. Adults with chronic nonspecific low back pain have demonstrated lower hip abductor and extensor strength on isometric dynamometry [7], while a systematic review reported heterogeneous hip electromyographic findings across different tasks [8]. Surface electromyography provides information on muscle electrical activity, but signal amplitude reflects neural excitation together with peripheral and technical influences and should not be interpreted as a direct measure of muscle force [9]. Its diagnostic performance and reliability also vary across flexion–extension–relaxation paradigms [10].

Current evidence remains fragmented. Recent MVIC-referenced sEMG studies have predominantly focused on trunk musculature, whereas investigations of hip-muscle activity have largely been conducted during functional tasks [8,11]. Therefore, this study compared sEMG activity of the erector spinae, rectus abdominis, gluteus maximus, and gluteus medius between adults with chronic nonspecific low back pain and asymptomatic controls.

2. MATERIALS AND METHODS

2.1 Study Design and Participants

This comparative cross-sectional study evaluated surface electromyographic (sEMG) activity during maximal voluntary isometric contraction (MVIC) in adults with chronic nonspecific low back pain (CNSLBP) and asymptomatic controls. The study was conducted at Hasanuddin University Hospital, Makassar, Indonesia, between October 2025 and March 2026 and was reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) recommendations for cross-sectional studies.

Adults aged 18–44 years were screened for eligibility. Participants with CNSLBP were eligible if they had axial, non-radiating low back pain persisting for at least 3 months, no identified specific spinal pathology, and a Numerical Rating Scale (NRS) score <6/10. Exclusion criteria were previous surgery involving the spine, abdomen, or tested musculature; neurological deficits; radiculopathy, spinal stenosis, compression fracture, infection, malignancy, cauda equina syndrome, ankylosing spondylitis, or another identified cause of low back pain; another trunk, abdominal, or hip condition potentially affecting muscle performance; regular resistance training targeting the trunk or hip muscles during the preceding 6 weeks; or inability to complete the sEMG assessment.

Asymptomatic controls were aged 18–44 years and had experienced no low back pain during the preceding 3 months. Controls were excluded if they had undertaken regular trunk or hip resistance training during the preceding 6 weeks or were unable to complete the sEMG protocol. Eligible participants were selected using simple random sampling.

The planned sample size was based on the a priori power calculation reported by Koch et al. [12], who similarly compared individuals with nonspecific low back pain and healthy controls using erector spinae sEMG. Their analysis indicated that 32 participants (16 per group) were required to detect an effect size of 0.65 with 80% power at a two-sided α of 0.05. Recruitment was increased to 20 participants per group to account for potential attrition, resulting in a target sample of 40 participants.

2.2 Clinical and Anthropometric Assessment

Age, sex, body weight, height, and body mass index (BMI) were recorded before sEMG testing. In the CNSLBP group, pain intensity was assessed using the 0–10 NRS, disability using the Oswestry Disability Index (ODI), and symptom duration in months. These variables were used to characterize the study population and assess baseline comparability between groups.

2.3 Surface Electromyography Acquisition and MVIC Protocol

Surface EMG activity was recorded using a NeuroTrac MyoPlus 4 Pro system (Verity Medical Ltd., United Kingdom) with disposable 20 × 20-mm surface electrodes. Before electrode placement, the skin was cleaned with alcohol and hair was removed when necessary. Paired electrodes were positioned over each muscle with an interelectrode distance of approximately 20 mm. Bilateral recordings were obtained from the erector spinae, rectus abdominis, gluteus maximus, and gluteus medius.

For the gluteus maximus, electrodes were positioned approximately midway between the lateral sacral region and the greater trochanter, whereas gluteus medius electrodes were positioned midway between the iliac crest and greater trochanter [13,14]. Erector spinae electrodes were placed approximately 2–3 cm lateral to the lumbar midline along the line extending from the caudal posterior superior iliac spine toward the L1–L2 interspace, according to the predefined protocol [13]. Rectus abdominis electrodes were positioned approximately 3 cm lateral to the midline between the umbilicus and pubic symphysis [15]. Identical skin preparation, electrode placement, and testing procedures were applied to both groups.

Each muscle was assessed during a standardized resisted MVIC. For the gluteus maximus, participants were positioned prone and performed resisted hip extension with manual resistance applied to the distal posterior thigh. The gluteus medius was assessed in side-lying during resisted hip abduction, with resistance applied to the distal lateral thigh. Erector spinae activity was assessed in the prone position with the lower extremities stabilized at the ankles while participants performed resisted trunk extension against manual resistance applied over the posterior scapular region. Rectus abdominis activity was assessed in the supine position with the knees flexed to 90° and the feet supported while participants performed resisted trunk flexion against resistance applied at the shoulders.

For each muscle, three 5-s contraction trials were performed with 15 s of rest between trials. A minimum rest interval of 3 min was provided between muscle assessments to minimize carry-over fatigue. Measurements were obtained bilaterally under standardized conditions in both groups. Testing was discontinued if pain, fatigue, or other symptoms prevented safe completion of the procedure.

2.4 Surface EMG Outcomes

The sEMG outcomes were work average (WAV), work average deviation (WAVDEV), and peak amplitude, expressed in microvolts (μV). WAV was prespecified as the primary sEMG outcome, whereas WAVDEV and peak amplitude were considered secondary outcomes. WAV represented the average sEMG amplitude recorded during the active contraction period, WAVDEV represented the dispersion of amplitude around the corresponding work average, and peak amplitude represented the maximum sEMG amplitude recorded during contraction.

These parameters were interpreted as indices of electrical muscle activity during MVIC rather than direct measures of mechanical muscle force. Surface EMG amplitude reflects neural excitation together with peripheral, anatomical, and technical factors and therefore should not be considered interchangeable with muscle strength [9]. Participant-level bilateral values were calculated as the arithmetic mean of the right and left recordings for each sEMG parameter.

2.5 Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics for Mac, version 30.0 (IBM Corp., Armonk, NY, USA). Continuous-variable distributions were assessed using the Shapiro–Wilk test. Normally distributed variables were summarized as mean ± standard deviation, whereas non-normally distributed variables were presented as median with first and third quartiles [median (Q1–Q3)]. Categorical variables were presented as frequencies and percentages.

Baseline continuous variables were compared between groups using the independent-samples t test when distributional assumptions were satisfied, whereas categorical variables were compared using Pearson's chi-square test. Because the sEMG outcomes were non-normally distributed, between-group comparisons were performed using exact two-sided Mann–Whitney U tests. Hodges–Lehmann location-shift estimates with 95% confidence intervals were reported.

Holm adjustment was applied separately across the four primary WAV comparisons and the eight secondary WAVDEV and peak-amplitude comparisons. All statistical tests were two-sided. Unadjusted $P<0.05$ was considered nominally statistically significant, while multiplicity-adjusted results were interpreted according to the Holm procedure.

3. RESULTS AND DISCUSSION

3.1 Participant characteristics

Forty participants were included, comprising 20 participants with chronic nonspecific low back pain (CNSLBP) and 20 asymptomatic controls. Age, sex distribution, and body mass index were comparable between groups (Table 1). Participants with CNSLBP had a median pain duration of 5.50 months and median NRS pain score of 3.00, while the mean ODI score was 13.20%.

Table 1. Participant characteristics

Characteristic	CNSLBP (n=20)	Asymptomatic controls (n=20)	*p* value
Age, years	29.80 ± 3.25	31.90 ± 3.37	0.052[a]
Female sex, n (%)	11 (55.0)	11 (55.0)	1.000[b]
Body mass index, kg/m²	25.42 ± 4.87	25.04 ± 4.09	0.793[a]
Pain duration, months	5.50 (4.25–6.00)	—	—
NRS pain score	3.00 (3.00–4.00)	—	—
ODI, %	13.20 ± 5.63	—	—

Notes: Data are presented as mean ± standard deviation, median (Q1–Q3), or n (%), according to distribution. [a]Independent-samples *t* test. [b]Pearson chi-square test. NRS, Numeric Rating Scale; ODI, Oswestry Disability Index; CNSLBP, chronic nonspecific low back pain.

3.2 Work average during maximal voluntary isometric contraction

Bilateral work average (WAV) was nominally lower in the CNSLBP group for the erector spinae and rectus abdominis (Table 2). The estimated location shifts were −24.50 μV for the erector spinae and −21.25 μV for the rectus abdominis. No between-group differences were observed for the gluteus maximus or gluteus medius. However, none of the four comparisons remained statistically significant after Holm correction.

Table 2. Between-group differences in bilateral sEMG work average during MVIC

Muscle	CNSLBP (n=20), median (Q1–Q3), μV	Asymptomatic controls (n=20), median (Q1–Q3), μV	Hodges–Lehmann location-shift estimate (95% CI), μV	*p* value	Holm-adjusted *p*
Erector spinae	51.75 (41.63–88.88)	75.50 (66.50–107.50)	−24.50 (−41.50 to −3.50)	0.026[a]*	0.104
Rectus abdominis	60.50 (42.25–86.00)	81.25 (60.25–135.63)	−21.25 (−48.00 to −0.50)	0.040[a]*	0.120
Gluteus maximus	88.50 (41.75–127.25)	76.75 (64.13–145.75)	−18.50 (−45.50 to 17.00)	0.277[a]	0.530
Gluteus medius	112.00 (63.13–201.50)	127.75 (104.88–188.88)	−26.25 (−66.00 to 20.00)	0.265[a]	0.530

Notes: Data are presented as median (Q1–Q3). Hodges–Lehmann estimates represent the location shift for CNSLBP relative to asymptomatic controls; negative values indicate lower values in the CNSLBP group. [a]Mann–Whitney U test. Holm correction was applied across the four WAV comparisons. *Unadjusted $p<0.05$. CI, confidence interval; MVIC, maximal voluntary isometric contraction; sEMG, surface electromyography; WAV, work average.

The distributions of WAV across the four muscles are shown in Figure 1. Individual observations demonstrated a downward shift in erector spinae and, to a lesser extent, rectus abdominis activity in the CNSLBP group, whereas substantial overlap between groups was evident for both gluteal muscles.

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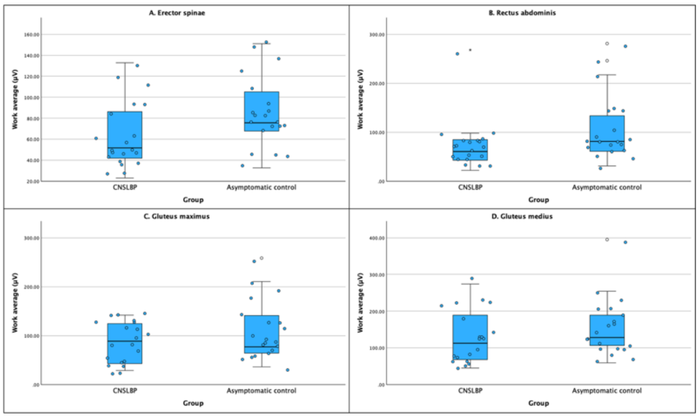

Figure 1. Distribution of bilateral surface electromyographic work average during maximal voluntary isometric contraction in participants with chronic nonspecific low back pain and asymptomatic controls. Panels show the (A) erector spinae, (B) rectus abdominis, (C) gluteus maximus, and (D) gluteus medius. Boxes represent the median and interquartile range, and individual points represent participant-level observations.

3.3 Secondary sEMG outcomes

Among the secondary outcomes, erector spinae WAVDEV and peak amplitude were nominally lower in participants with CNSLBP than in asymptomatic controls (Table 3). The Hodges–Lehmann estimates were −5.88 μV for WAVDEV and −52.25 μV for peak amplitude. No nominal differences were detected for the remaining trunk or gluteal outcomes. None of the eight secondary comparisons remained statistically significant after Holm correction.

Table 3. Secondary sEMG outcomes during maximal voluntary isometric contraction

Outcome	Muscle	CNSLBP (n=20), median (Q1–Q3), μV	Asymptomatic controls (n=20), median (Q1–Q3), μV	Hodges–Lehmann location-shift estimate (95% CI), μV	*p* value	Holm-adjusted *p*
WAVDEV	Erector spinae	12.25 (10.31–20.50)	20.25 (15.63–31.00)	−5.88 (−11.00 to −1.50)	0.010[a]*	0.080
	Rectus abdominis	18.50 (13.13–27.00)	25.50 (17.88–38.38)	−7.00 (−16.00 to 0.50)	0.068[a]	0.408
	Gluteus maximus	28.00 (12.63–35.75)	27.25 (21.00–42.88)	−6.00 (−14.80 to 3.90)	0.221[a]	0.870
	Gluteus medius	32.75 (18.63–49.25)	37.00 (27.13–54.88)	−6.25 (−17.50 to 6.50)	0.289[a]	0.870
Peak	Erector spinae	125.25 (84.75–196.50)	184.00 (132.13–294.50)	−52.25 (−112.50 to −2.00)	0.043[a]*	0.301
	Rectus abdominis	170.50 (126.50–253.88)	200.75 (163.13–447.38)	−36.50 (−108.50 to 19.50)	0.183[a]	0.870
	Gluteus maximus	240.00 (162.63–299.75)	270.50 (188.25–395.25)	−42.75 (−133.00 to 32.50)	0.277[a]	0.870
	Gluteus medius	299.25 (158.50–440.88)	369.25 (226.13–536.75)	−77.50 (−207.00 to 36.50)	0.174[a]	0.870

Notes: Data are presented as median (Q1–Q3). Hodges–Lehmann estimates represent the location shift for CNSLBP relative to asymptomatic controls; negative values indicate lower values in the CNSLBP group. [a]Mann–Whitney U test. Holm correction was applied across the eight secondary comparisons. *Unadjusted $p<0.05$. CI, confidence interval; MVIC, maximal voluntary isometric contraction; sEMG, surface electromyography; WAVDEV, work average deviation.

3.4 Discussion

In the unadjusted analyses, participants with chronic nonspecific low back pain (CNSLBP) showed lower bilateral surface electromyographic (sEMG) work average (WAV) during maximal voluntary isometric contraction (MVIC) of the erector spinae (ES) and rectus abdominis (RA), together with lower ES WAVDEV and peak amplitude. No corresponding differences were observed for the gluteus maximus or gluteus medius. However, none of these findings remained statistically significant after correction for multiple comparisons and should therefore be interpreted as exploratory signals rather than evidence of a selective neuromuscular deficit. This cautious interpretation is particularly relevant because back-muscle dysfunction in chronic low back pain is heterogeneous across individuals and clinical phenotypes [3], while the diagnostic performance of sEMG varies considerably even within flexion–extension–relaxation paradigms [10].

The lower ES amplitude observed during MVIC should not be generalized to ES behavior across other tasks. Balasch-Bernat et al. [4], for example, reported higher normalized ES and multifidus activity in individuals with continuous chronic low back pain than in healthy controls during the concentric and holding phases of a modified Biering–Sørensen task. Conversely, Koch et al. [12] found no between-group differences in lumbar ES activity during quiet standing in a similarly sized nonspecific low back pain case-control sample. Using high-density sEMG during submaximal lumbar extension, Arvanitidis et al. [16] demonstrated altered sEMG–torque relationships and different regional redistribution of ES activity as torque increased. Collectively, these findings indicate that altered ES behavior in chronic low back pain is strongly dependent on contraction intensity, task demands, and the spatial and analytical characteristics of EMG measurement.

A similar qualification applies to the nominally lower RA WAV. Evidence from other paradigms does not support a uniform reduction in abdominal muscle recruitment in chronic low back pain. Ershad et al. [5] reported greater internal and external oblique activation during unstable dynamic loading, consistent with increased trunk co-activation under specific mechanical demands. Saito et al. [6] found that the overall organization of trunk-muscle synergies was largely preserved in young adults with chronic low back pain, although variability differed between ES-related synergies and those recruited during more demanding stability tasks. Massé-Alarie et al. [17] further demonstrated modified trunk nociceptive withdrawal reflex organization, including more frequent abdominal responses to rib stimulation and less frequent ES responses. Although these paradigms differ substantially from voluntary MVIC, they support context-dependent neuromuscular reorganization rather than a stereotyped pattern of abdominal hypoactivation.

The absence of between-group differences in gluteal WAV should likewise not be interpreted as evidence of preserved hip strength. Pizol et al. [7] demonstrated lower isometric hip abductor and extensor strength in adults with chronic nonspecific low back pain using dynamometry. A subsequent systematic review of 54 observational studies found that reduced hip abductor and extensor strength may coexist with greater gluteus maximus activation during specific tests and functional tasks [8]. Thus, dynamometric force and sEMG amplitude provide related but non-equivalent information, and the present gluteal findings do not exclude clinically relevant hip-muscle dysfunction.

More broadly, the present findings should be considered within the substantial variability of motor behavior in nonspecific low back pain. Moissenet et al. [18] identified 121 movement and 150 muscular-activity biomarkers across 92 studies, yet only a minority had undergone extensive evaluation of their measurement properties, highlighting the lack of a robust standardized biomechanical approach to CNSLBP. Pain-related threat may further contribute to task-dependent motor behavior. Ippersiel et al. [19] reported weak-to-moderate associations between fear or catastrophizing and guarded motor behavior during flexion-based tasks, whereas associations were inconsistent across other movements. These observations further caution against interpreting a single MVIC sEMG measure as a stand-alone marker of CNSLBP.

Interpretation of WAVDEV and peak amplitude requires additional restraint. WAVDEV was treated as a device-derived measure of dispersion around WAV and should not be regarded as a validated index of motor-control consistency. Similarly, peak amplitude represents the highest recorded electrical amplitude rather than maximal mechanical force. Surface EMG amplitude reflects overall muscle excitation together with peripheral and technical determinants, including the sampled muscle region, electrode configuration, tissue characteristics, and signal conditioning [9,20]. Raw microvolt values therefore cannot be translated directly into muscle strength, particularly in the absence of simultaneous torque or dynamometric measurements.

The clinical implication is not that the ES or RA should be treated in isolation, but that trunk and hip function should be evaluated using complementary measures. Exercise therapy has moderate-certainty evidence for reducing pain in chronic nonspecific low back pain, although improvements in functional limitation are generally smaller [21]. Motor-control rehabilitation has been associated with changes in lumbopelvic movement and muscle-recruitment patterns [22], while exercise-based interventions can modify trunk sEMG measures [23]. Importantly, Blanco-Giménez et al. [24] observed improvements in pain that were not consistently accompanied by changes in RA or multifidus electrical activity, reinforcing that normalization of a single sEMG measure should not be considered necessary for clinical improvement.

Strengths of this study include standardized bilateral testing, complete participant-level data, exact nonparametric inference, reporting of effect estimates with 95% confidence intervals, and explicit correction for multiple comparisons. Several limitations should nevertheless be considered. The study involved a small single-center sample and a relatively mild CNSLBP phenotype, limiting generalizability. The cross-sectional design precludes temporal or causal inference. Raw rather than normalized sEMG amplitudes were analyzed, simultaneous torque or dynamometric measurements were unavailable, and bilateral averaging may have obscured side-specific adaptations. Future studies should prespecify a limited number of primary sEMG outcomes, incorporate concurrent mechanical measurements and standardized normalization procedures, and evaluate broader clinical phenotypes longitudinally. Overall, the present data suggest task-specific differences in trunk electrical activity during MVIC, particularly involving the ES and RA, but do not establish a generalized or muscle-specific neuromuscular deficit in CNSLBP [3,9].

4. CONCLUSION

Adults with CNSLBP showed lower bilateral sEMG work average of the erector spinae and rectus abdominis during MVIC in unadjusted analyses, while gluteus maximus and gluteus medius activity did not differ between groups. Erector spinae WAVDEV and peak amplitude were also nominally lower. However, none of these differences remained statistically significant after correction for multiple comparisons. These findings therefore suggest task-specific alterations in trunk muscle electrical activity rather than a generalized or muscle-specific neuromuscular deficit. Surface EMG findings should be interpreted alongside clinical and mechanical measures, and larger studies using standardized normalization and concurrent force assessment are needed to determine their clinical relevance.

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AUTHOR CONTRIBUTIONS

Michael Susanto: Conceptualization, Methodology, Investigation, Data Curation, Formal Analysis, and Writing – Original Draft.

Yose Waluyo: Conceptualization, Methodology, Supervision, Validation, and Writing – Review & Editing.

Nuralam Sam: Methodology, Supervision, Validation, and Writing – Review & Editing.

Andi Alfian Zainuddin: Methodology, Formal Analysis, Validation, and Writing – Review & Editing.

Nilla Mayasari: Methodology, Supervision, Validation, and Writing – Review & Editing.

Anshory Sahlan: Methodology, Supervision, Validation, and Writing – Review & Editing.

All authors critically reviewed the manuscript, approved the final version, and agreed to be accountable for the integrity and accuracy of the work.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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ETHICS STATEMENT

The study protocol was approved by the Health Research Ethics Committee, Faculty of Medicine, Hasanuddin University (Approval No. 712A/UN4.6.4.5.31/PP36/2025; Protocol No. UH25070532). All participants received information regarding the study procedures and provided written informed consent before participation. Participant confidentiality was maintained throughout data collection and analysis. The study was conducted in accordance with the principles of the Declaration of Helsinki.

DATA AVAILABILITY STATEMENT

The data supporting the findings of this study are available from the corresponding author upon reasonable request, subject to applicable ethical and institutional restrictions.

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