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Métricas de entropia para analisar a regularidade do movimento do tronco na dor lombar crônica inespecífica: insights de uma revisão sistemática.

BRASÍLIA, DF
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Orientador: Prof. Dr. Wagner Rodrigues Martins.

Co-Orientador: Profa. Dra. Elaine Cristina Leite.

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DEDICATÓRIA

P*rimeiramente, a Deus, por me conceder força, sabedoria e perseverança ao longo desta trajetória.*

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RESUMO

A dor lombar crônica inespecífica (DLCI) é uma das principais causas de incapacidade funcional no mundo, com impactos expressivos na saúde pública. Evidências crescentes indicam que a DLCI está associada a alterações no controle motor do tronco, particularmente na variabilidade e regularidade dos movimentos. Este trabalho teve como objetivo realizar uma revisão sistemática da literatura para investigar o uso de métricas de entropia na avaliação da regularidade dos movimentos do tronco em indivíduos com DLCI, comparando-os a indivíduos saudáveis. Foram incluídos estudos transversais que utilizaram medidas de entropia, como entropia simples (SampEn) e Entropia multiescala (MSE) durante tarefas motoras como marcha, postura e flexo-extensão do tronco. A busca foi conduzida em sete bases de dados e em literatura cinzenta, sem restrições de idioma ou data, seguindo as diretrizes PRISMA 2020. A avaliação metodológica foi realizada com a ferramenta da Joanna Briggs Institute, que avalia a qualidades de estudos trasnversais. Os achados apontaram que indivíduos com DLCI apresentaram maior regularidade (menor entropia) em tarefas posturais e de marcha, e menor regularidade (maior entropia) em tarefas dinâmicas, como flexo-extensão, indicando alterações dependentes da tarefa. Esses padrões refletem uma redução na adaptabilidade do sistema motor, alinhando-se à perspectiva dos sistemas dinâmicos não lineares. No entanto, a heterogeneidade metodológica entre os estudos limita a comparabilidade dos dados e reforça a necessidade de padronização dos protocolos de coleta e análise. Do ponto de vista clínico, a entropia surge como ferramenta promissora para detecção de disfunções motoras sutis, com potencial aplicação na avaliação funcional e no monitoramento terapêutico em fisioterapia. No campo da pesquisa, os achados reforçam a relevância de abordagens baseadas na complexidade para compreender os mecanismos motores associados à dor crônica, além de incentivar o desenvolvimento de biomarcadores objetivos de controle motor.

Palavras-chave: dor lombar crônica inespecífica; entropia; variabilidade do movimento; controle motor; fisioterapia; complexidade

ABSTRACT

Chronic non-specific low back pain (CNLBP) is a leading cause of functional disability worldwide and imposes a significant burden on public health systems. Emerging evidence suggests that CNLBP is associated with motor control alterations, particularly in trunk movement variability and regularity. This study aimed to conduct a systematic review of the literature to investigate the use of entropy-based metrics in assessing trunk movement regularity in individuals with CNLBP compared to healthy controls. Cross-sectional studies that applied entropy measures (e.g., SampEn, MSE) during motor tasks such as gait, posture, and trunk flexion-extension were included. A comprehensive search was conducted across seven scientific databases and grey literature sources, with no restrictions on language or publication date, following the PRISMA 2020 guidelines. Methodological quality was assessed using the Joanna Briggs Institute Critical Appraisal Checklist. Findings revealed that individuals with CNLBP exhibited increased regularity (lower entropy) during postural and gait tasks and decreased regularity (higher entropy) during dynamic tasks, such as trunk flexion-extension, indicating task-dependent motor alterations. These patterns reflect reduced adaptability of the motor system, consistent with nonlinear dynamical systems theory. However, significant methodological heterogeneity across studies limits data comparability and highlights the need for standardization in entropy analysis protocols. Clinically, entropy measures show promise as objective tools for identifying subtle motor dysfunctions and may contribute to functional assessment and rehabilitation monitoring in physical therapy. In research, these findings emphasize the value of complexity-based approaches in understanding motor control mechanisms associated with chronic pain and support the development of objective motor biomarkers.

Keywords: chronic non-specific low back pain; entropy; movement variability; motor control; physical therapy; complexity.

SUMÁRIO

1. INTRODUÇÃO

A dor lombar crônica inespecífica (DLCI) constitui uma das condições musculoesqueléticas mais prevalentes mundialmente, sendo responsável por impactos significativos na qualidade de vida, no desempenho funcional e na participação social dos indivíduos afetados (James et al., 2018). Além disso, representa uma das principais causas de incapacidade laboral e contribui substancialmente para o ônus socioeconômico global em saúde pública (Alfalogy et al., 2023).

Para investigar a associação entre fatores de risco da DLCI e o comportamento biomecânico dos movimentos do tronco, tem-se utilizado a análise cinética e cinemática, na tentativa de compreender possíveis mecanismos de defesa do sistema musculoesquelético (Lamoth et al., 2006; Kongoun et al., 2024). Contudo, os parâmetros biomecânicos lineares demonstram evidência limitada e uso inconsistente quanto à sua capacidade de gerar desdobramentos clínicos significativos sobre a dor lombar (Sung et al., 2019). A dificuldade em associar a DLCI a parâmetros cinemáticos pode estar relacionada à natureza complexa do controle postural e do movimento (Van Emmerik et al., 2016). O controle motor do tronco e a coordenação neuromuscular durante tarefas como marcha, postura ereta e movimentos de flexão/extensão envolvem interações dinâmicas entre partes que se organizam de forma imprevisível, com comportamentos emergentes que alteram o contexto e as prioridades dos próprios elementos que compõem o sistema (Plsek et al., 2001).

Sob a perspectiva dos sistemas dinâmicos não lineares, a regularidade do movimento é interpretada como um fenômeno funcional que reflete a complexidade e a flexibilidade do sistema motor (Kosciessa et al., 2020). Essa abordagem propõe que sistemas biológicos saudáveis apresentam variabilidade estruturada — uma forma de "caos funcional" — que permite adaptação eficiente a perturbações internas e externas (Stergiou & Decker, 2011). A perda dessa variabilidade, seja por excesso de regularidade ou por desorganização aleatória, indica uma redução na complexidade do sistema e, consequentemente, uma menor capacidade adaptativa.

Uma maneira de quantificar a regularidade dos movimentos temporais associados à dinâmica funcional é por meio de medidas de entropia (Pincis et al. 1994). Essas métricas permitem identificar padrões sutis de organização do movimento que não são captados por métodos lineares tradicionais (Piergiovanni & Terrier, 2024). Valores reduzidos de entropia indicam maior previsibilidade (isto é, maior regularidade), enquanto valores aumentados podem refletir desorganização ou perda do controle motor fino, dependendo do contexto da tarefa (Alsubaie et al., 2023).

Apesar do crescente interesse na aplicação de métricas de entropia para investigar padrões motores em indivíduos com DLCI, a literatura permanece fragmentada e metodologicamente heterogênea. Variáveis como o tipo de tarefa analisada, a frequência de amostragem, os parâmetros de cálculo da entropia e a escala temporal utilizada limitam a comparação entre os estudos e dificultam a tradução clínica dos achados.

A ausência de padronização nas variáveis utilizadas para a análise da complexidade, por meio do cálculo de entropia, em indivíduos com dor lombar crônica inespecífica (DLCI) parece impactar diretamente os resultados dos estudos existentes. Diante desse cenário, torna-se necessário sistematizar criticamente as evidências disponíveis, com foco nas características metodológicas adotadas e nos padrões de regularidade identificados.

2. OBJETIVOS

O objetivo do presente trabalho é sintetizar as evidências disponíveis na literatura científica, por meio de uma revisão sistemática, acerca do uso de métricas de entropia na avaliação da regularidade do movimento do tronco em indivíduos com dor lombar crônica inespecífica, comparando-os a indivíduos saudáveis.

ARTIGO: Entropy Metrics for Analyzing Trunk Movement Regularity in Chronic Non-specific Low Back Pain: Insights from a Systematic Review

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Introduction

Chronic non-specific low back pain (CNLBP) is one of the most prevalent musculoskeletal disorders worldwide, leading to functional impairments, reduced quality of life, and a substantial socioeconomic burden (1). CNLBP is associated with altered motor control in the kinematic chains, such as gait dysfunctions (2). Moreover, changes in trunk coordination and erector spine activity have been reported as direct consequences of CNLBP (3). Trunk neuromuscular adaptations affect the body's ability to execute stable movements across different tasks, leading to compensatory strategies and altered postural control (4).

The framework of non-linear dynamics emphasizes the importance of the regularity or irregularity of temporal movements for functional network dynamics (5). For example, to assess the dynamics of a biological system, the degree of uncertainty can be investigated by entropy. This measure is related to the amount of information needed to describe the biological process (6). Different entropy calculations have demonstrated how constraints in the motor control network (e.g., CNLBP) impact motor coordination, providing insights into the regularity of movement patterns, and have been used as a relevant index of complexity (7), which traditional linear metrics fail to detect (8,9). Methodological advances, such as multiscale entropy (MSE), have become essential for quantifying the regularity of time series across different health conditions. For example, increased regularity in a trunk kinematic time series (i.e., a significantly reduced entropy value) has been observed in individuals with CNLBP, indicating reduced motor control adaptability, that may be associated with limited biomechanical compensations during daily activities (10).

Although studies on non-linear dynamics have increased in recent decades, investigations into the association of pain states with entropy patterns still present many gaps, such as consensus regarding how CNLBP affects trunk movement regularity across diverse motor tasks (11). Additionally, methodological heterogeneity, including variations in sampling frequencies, entropy parameters, and study designs, complicates the synthesis of findings in studies of CNLBP. To bridge this gap, we conducted a systematic review to synthesize the current evidence on CNLBP and trunk movement regularity, providing an estimation of group differences between individuals with CNLBP and healthy controls,

Thus, the current systematic review aims to compare entropy measures of trunk kinematic variables in order to investigate group differences in regularity between individuals with and without CNLBP. We hypothesized that individuals with CNLBP exhibit greater movement regularity (i.e., lower entropy values) across different trunk kinematic tasks, reflecting reduced motor control adaptability.

Objective

Thus, the current systematic review aims to compare entropy measures of trunk kinematic variables in order to investigate group differences in regularity between individuals with and without CNLBP. We hypothesized that individuals with CNLBP exhibit greater movement regularity (i.e., lower entropy values) across different trunk kinematic tasks, reflecting reduced motor control adaptability.

Methods

Protocol and Registration

This study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines (12). Additionally, it was registered with the International Prospective Register of Systematic Reviews (PROSPERO) under registration number CRD42020187731 (13).

Eligibility Criteria

Original analytical Cross-sectional studies comparing trunk kinematic regularity between individuals with CNLBP and healthy controls were included. We excluded systematic reviews, case reports, case series, and interventional studies. Only observational cross-sectional designs with group comparisons were included. Studies without a healthy control group were also excluded.

We included studies of adult participants (≥18 years), both with and without CNLBP lasting over 12 weeks. Eligible studies had to evaluate trunk kinematic variables using entropy-based techniques, with data collected during, before, or after performing motor tasks (e.g., sitting posture, gait, trunk flexion/extension).

Sources and Search Strategy

A comprehensive electronic search was conducted across multiple databases, including PubMed, Web of Science, CINAHL, SPORTDiscus, Scopus, LILACS, and Embase. BASE and Google Scholar engines were also assessed to incorporate gray literature sources. Text-words and controlled vocabulary terms (e.g., MeSH, Emtree) were selected to capture core concepts and ensure a comprehensive search. Vocabularies included descriptors related to low back pain ("low back pain," "chronic low back pain," "non-specific low back pain"), movement analysis ("kinematics," "motor control," "trunk motion"), and entropy-based metrics ("regularity," "approximate entropy," "SampEn," "entropy"). To reduce restrictions in this phase that could lead to bias, affecting the study conclusions, no restrictions regarding language or publication period were applied (14). No filters regarding language, publication type, or date were applied to avoid restricting search sensitivity.

Selection Process

The files extracted from each database were imported into the Rayyan Systematic Review Platform (https://www.rayyan.ai/). The first step is removal of duplicate records. Subsequently, two independent blinded reviewers screened the titles and abstracts. The same reviewers assessed the full texts of potentially eligible studies when necessary. After applying the inclusion criteria at all screening phases, any disagreements regarding the final list of included studies were resolved by a third assessor. The entire selection process was conducted between September and November 2024.

Data Extraction and Summary

Data extraction was conducted independently by two reviewers using Google Forms (electronic form) (15). The process was structured into multiple phases: 1) Study identification and characteristics, 2) Participant information, 3) Motor tasks and kinematic data, 4) Entropy technical parameters, and 5) Risk of bias assessment. The included studies were summarized based on key methodological variables and results. Data synthesis focused on: 1) Entropy-based movement regularity, 2) Task-specific differences, 3) Methodological consistency, and 4) Influence of risk of bias.

Critical Appraisal Tool for Analytical Cross-Sectional Studies

The Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Analytical Cross-Sectional Studies is a standardized tool developed to assess the methodological quality of cross-sectional studies (16). Two independent reviewers applied the JBI critical appraisal tool, and a third assessor resolved discordances in the final analysis.

The checklist consists of eight key criteria, each addressing a potential source of bias: 1) clearly defined inclusion criteria – determines whether the study specifies well-defined inclusion and exclusion criteria before participant recruitment; 2) detailed description of study subjects and setting – ensures that the study provides sufficient details about the population, setting, and timeframe, allowing comparability with other studies; 3) valid and reliable exposure measurement – evaluates whether the method used to measure exposure is appropriate, standardized, and comparable to a gold standard; 4) use of objective and standardized criteria for condition measurement – assesses whether the study employs established diagnostic criteria or validated definitions to classify participants; 5) identification of confounding factors – determines whether the study recognizes potential confounders that could influence the observed relationships; 6) strategies to address confounding factors – examines whether the study implements matching, stratification, or multivariate analysis strategies to minimize confounding effects; 7) valid and reliable outcome measurement – ensures that outcome variables are measured using validated instruments or standardized assessment methods; and 8) appropriate statistical analysis – assesses whether the statistical methods used are suitable for the study design and correctly account for confounders. Each criterion is assessed as yes, no, unclear, or not applicable.

Results

Results of Study Searches and Characteristics

A flow diagram summarizing the study selection process is shown in Figure 1. Table 1 presents the included studies, study designs, and publication indicators. Table 2 shows the characteristics of the participants, motor tasks, and trunk kinematic measurements. Five cross-sectional studies met the inclusion criteria (11,17–20), comprising 195 participants with and without CNLBP. The mean age of participants ranged from 25.5 to 56.75 years, with sample sizes varying from 16 to 86 individuals.

Figure 1 – PRISMA flow diagram for the search and selection process.

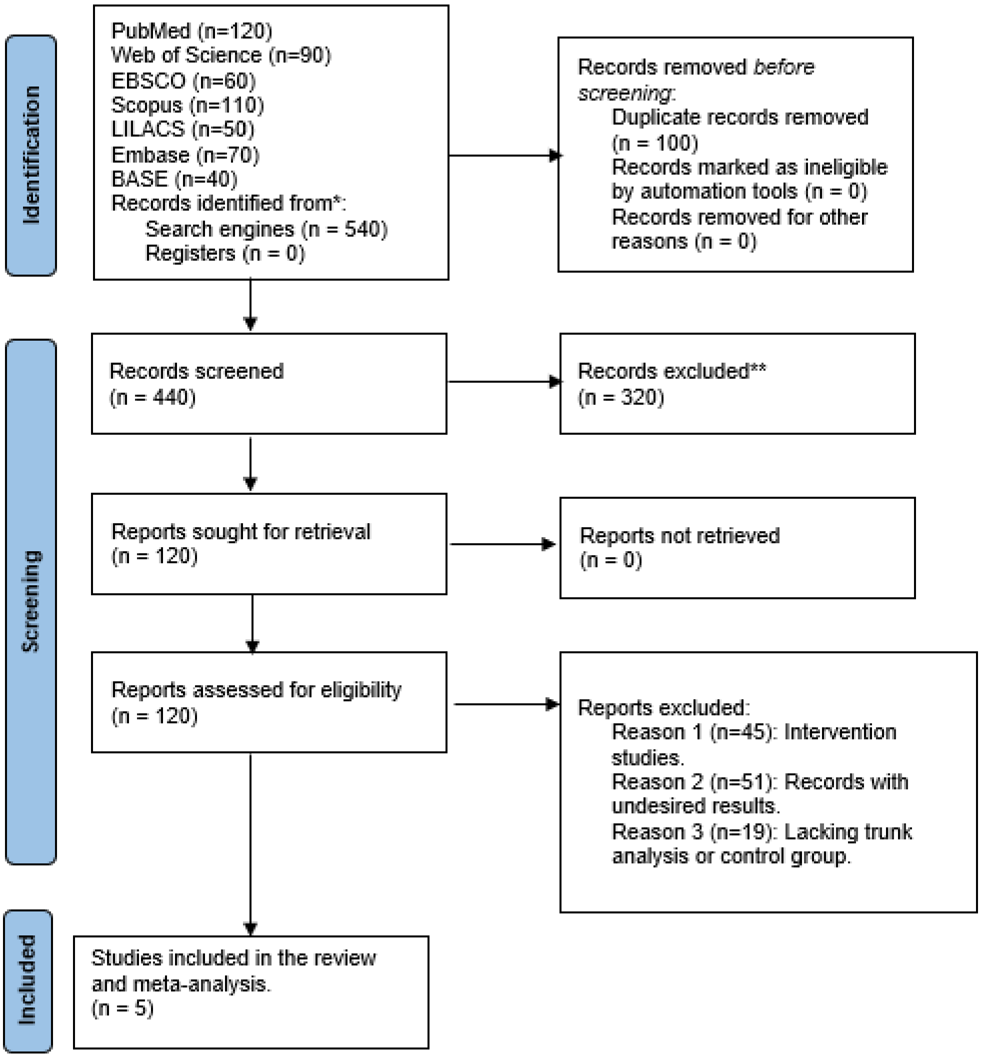

Table 1 – Studies included in the current work and publication indicators.

Author (Year, Country)	Study Title	Study Type	Conflict of Interest	Declared Financing
Nishi et al. (2021,	Changes in trunk regularity and stability	Cross-sectional	No	No

Japan)	of gait in patients with chronic low back pain			
Bauer et al. (2017, Switzerland/ Finland)	The effect of muscle fatigue and low back pain on lumbar movement regularity and complexity	Cross-sectional	No	NR
Shokouhyan et al. (2020, Iran)	Linear and non-linear dynamic methods toward investigating proprioception impairment in non-specific low back pain patients	Cross-sectional	No	No
Shokouhyan et al. (2022) Iran)	Distinction of non-specific low back pain patients with proprioceptive disorders from healthy individuals by linear discriminant analysis	Cross-sectional	No	No
Oliosi et al. (2024 Portugal)	Exploring the real-time regularity and complexity of sitting patterns in office workers with non-specific chronic spinal pain and pain-free individuals	Cross-sectional	No	NR

Legend: NR: not reported.

The studies were published from 2017 to 2024, reflecting growing interest in entropy-based analysis of CNLBP. The most recent study was conducted by Oliosi et al. (18), and the earliest study by Bauer et al. (11). Geographically, the studies were conducted across five countries (Japan, Iran, Portugal, Switzerland, and Finland) spanning two continents (Asia and Europe). This distribution highlights the interest of global research in entropy-based analyses of CNLBP, with contributions from both Western and Eastern institutions.

Regarding participant characteristics, all studies included both CNLBP individuals and healthy control groups, ensuring appropriate group comparisons. Shokouhyan et al. (19,22) assessed 40 male participants (20 CNLBP, 20 controls), with a mean age of 25.5 years in control and 24.5 years in CNLBP individuals. Bauer et al. (11) included 86 participants (59 CNLBP, 27 controls), covering an age range of 18 to 65 years. Oliosi et al. (18) studied 16 office workers (10 with chronic spinal pain, 6 controls), with mean ages of 51.3 years (controls) and 54.0 years (CSP group), 80% of whom were female. Nishi et al. (17) included 40 participants (20 CNLBP, 20 controls), with mean ages of 56.75 years (controls) and 54.05 years (CNLBP group), with 40–45% female representation.

Recent studies (2021–2024) focused on real-world motor assessments (e.g., posture monitoring in daily-life settings), while earlier work (2017–2020) prioritized controlled laboratory analyses of trunk movement regularity. The variation in participant demographics, methodologies, and entropy computation techniques underscores the need for standardization in future research to ensure cross-study comparability.

Motor tasks and kinematic data collection.

The included studies investigated trunk movement regularity using a variety of motor tasks and entropy-based kinematic analyses. Shokouhyan et al. (2020, 2022) applied vibration stimuli to the soleus and lumbar muscles to alter proprioceptive input under different conditions. In the 2020 study, trunk stability was assessed while participants externally induced proprioceptive illusions through vibratory stimulation (Entropy Metric: SampEn; Axis: Y-axis [ML direction]; Kinematic Measure: Trunk angle; Equipment: Vicon Motion Capture System). In the 2022 study, postural control was analyzed under eight different conditions, including variations in surface stability (rigid vs. foam) and vibration patterns on triceps and multifidus muscles (Entropy metric: SampEn; Axis: Y-axis [ML direction]; Kinematic measure: trunk sagittal angle; Equipment: Vicon Motion Capture System). Bauer et al. (2017) and Nishi et al. (2021) evaluated dynamic movement tasks. Bauer et al. (2017) investigated lumbar movement regularity during repetitive flexion-extension cycles, in which participants performed 20 cycles of seated lumbar flexion-extension before and after an isometric endurance test (Entropy metric: SampEn); Axis: X-axis [Flexion-Extension]; Kinematic measure: lumbar angular velocity; Equipment: IMUs [placed at L1 and S2]). Nishi et al. (2021) investigated gait tasks in which the participants walked for more than 60 seconds at their preferred speed on an indoor 30m loop, followed by three days of continuous movement monitoring using a triaxial accelerometer (Entropy metric: SampEn; Axis: not specified; Kinematic measure: center of mass displacement; Equipment: force platform). One study adopted an ecological methodology, analyzing postural control in real-life settings. Oliosi et al. (2024) monitored sitting postures in office workers over five consecutive workdays, capturing their habitual movements during regular office tasks (Entropy metric: SampEn; Axis: mediolateral [Y-axis] and anterior-posterior [X-axis]; Kinematic measure: trunk acceleration; Equipment: smartphone accelerometer).

Table 2. Participants, motor tasks, and trunk kinematic measurements.

Author (Year, Country)	Participants	Motor Task	Trunk kinematic data collection
Shokouhyan et	40 participants (20 NSLBP, 20	Alter proprioception input. Alter	SampEn. Y-axis (ML direction) to

al. (2020, Iran)	Control), Males only. Mean age: Control = 25.5 (0.7) years; NSLBP = 24.5 (0.9) years. Inclusion criteria for NSLBP patients: Free of vestibular disorders, radiculopathy, neurological, or respiratory disease, as well as any surgical procedures involving the spine, neck, chest, or lumbar.	proprioception of the soleus and lumbar muscles using vibrator apparatus equipped with four brushless DC motors to produce muscle vibration. When vibrations were applied to the lumbar area, an illusion of extension was externally induced, causing the CNS to execute a forward incline.	assess trunk angle (Vicon Motion Capture System).
Shokouhyan et al. (2022, Iran)	40 participants (20 NSLBP, 20 Control), Males only. Mean age: Control = 25.5 (0.7) years; NSLBP = 24.5 (0.9) years. To meet the inclusion criteria, the NSLBP patients had to be free of any neurological, respiratory, or cardiovascular disease and any spinal, neck, chest, or lumbar surgeries.	Postural control with altered proprioception. Vibration was applied to the soleus and lumbar muscles using a custom-built device with four brushless DC motors (70 Hz, 0.5 mm amplitude). Participants performed eight conditions: standing on rigid or foam surfaces, with no vibration, triceps vibration, multifidus vibration, or both.	SampEn Y-axis (ML direction). Trunk sagittal angle. (Vicon Motion Capture System).
Bauer et al. (2017, (Switzerland/ Finland)	Fifty-nine participants with sub-acute or chronic LBP and 27 asymptomatic participants aged between 18 and 65 years were recruited from physiotherapy practices. To be eligible, participants with LBP had to fulfill the following inclusion criteria: - A current episode of sub-acute or chronic non-specific LBP that persisted for four weeks or longer. - A mean LBP intensity of ≥1 on the numeric rating scale (NRS) over the last four weeks. - A moderate disability is defined as an Oswestry Disability Index (ODI) > 8%. - A low level of psychosocial risk factors is	Repeated flexion-extension test. Participants performed 20 cycles of lumbar flexion-extension in a seated position (3s per cycle) before and after an isometric endurance test to fatigue lumbar musculature (Biering-Sorensen test).	The lumbar movement was measured using IMUs (placed at L1 and S2). SampEn. X-axis lumbar angular velocity (flexion-extension).

	defined as fewer than four points on the psychosocial subscale of the STarT Back screening tool.		
Oliosi et al. (2024, Portugal)	16 office workers (10 CSP, 6 Control). Mean age: Control = 51.3 (4.41) years; CSP = 54.0 (6.51) years. Sex (% Female): Control = 50.0%; CSP = 80.0%. The CSP group included individuals with non-specific spinal pain persisting for at least three months without an identifiable underlying cause, based on IASP and ICD-11 criteria. The control group consisted of individuals with no spinal or lower limb pain history.	Real-time monitoring of sitting posture during office work was performed. Participants were monitored for five consecutive workdays while performing regular office tasks. Data were collected using a smartphone mounted on the chest via a harness.	SampEn. Medio-lateral (Y-axis) and anterior-posterior (X-axis) trunk acceleration.

Abbreviations: CNS – Central Nervous System; CSP – Chronic Spinal Pain; IMU – Inertial Measurement Unit; IASP – International Association for the Study of Pain; ICD-11 – International Classification of Diseases 11th Revision; LBP – Low Back Pain; ML – Medio-Lateral; NSLBP – Non-Specific Low Back Pain; NRS – Numeric Rating Scale; ODI – Oswestry Disability Index; SampEn – Sample Entropy; STarT Back – Subgrouping for Targeted Treatment Back Screening Tool; Vicon – Vicon Motion Capture System.

Entropy-based metrics

The entropy parameters (Table 3) varied considerably across studies, reflecting heterogeneity in the methodological approaches. Among the included studies, SampEn was the most frequently applied metric, used in four studies, while MSE was exclusively employed in one study. The input parameters for entropy calculations varied significantly: the embedding dimension (m) ranged from 2 to 3, the tolerance value (r) varied between 0.15 and 0.2, and the number of scales in MSE ranged from 5 to 10. Sampling frequencies ranged from 50 Hz to 500 Hz, influencing the temporal resolution of entropy calculations.

Qualitative results

The findings from the included studies demonstrate significantly different entropy patterns in individuals with CNLBP. Despite methodological differences, the studies consistently reported alterations in movement regularity when comparing CNLBP individuals with healthy controls. Two studies that investigated postural control with proprioceptive perturbations (Shokouhyan et al., 2020, 2022) found that individuals with CNLBP exhibited significantly lower SampEn values, i.e., increased movement regularity in the mediolateral (Y-axis) direction. In contrast, Bauer et al. (2017) analyzed lumbar movement during seated flexion-extension cycles and reported higher SampEn values (reduced movement regularity) in the flexion-extension (X-axis) direction. Regarding dynamic tasks, Nishi et al. (2021) examined trunk acceleration during gait using MSE. The study reported lower MSE (reduced movement regularity) during walking values across multiple time scales in both the anterior-posterior (X-axis) and mediolateral (Y-axis) directions. Finally, Oliosi et al. (2024) monitored real-world sitting posture over five workdays. The authors found no statistically significant differences in SampEn values in the anterior-posterior (X-axis) and mediolateral (Y-axis) directions.

Table 3 – Entropy methodological key procedures and conclusions between studies.

Author (Year, Country)	Time-series length (s)	Time scale analyzed	Sampling rate (Hz) & Equipment	Parameters (m, r, U, N)	Filtering	Findings
Bauer et al. (2017, Switzerland /Finland)	60 s	Not reported	200 Hz – Inertial Measurement Units (IMUs) Valedo® Motion (Hocoma AG, Switzerland) placed at L1 and S2	m=2, r=0.2×SD, N=600	Low-pass Butterworth filter (6 Hz cutoff, 2nd order, zero-phase)	SampEn was lower in CLBP, indicating increased regularity in lumbar angular velocity (X-axis) during flexion-extension cycles in a seated position.
Nishi et al. (2021, Japan)	>60 s per walking epoch	τ-values (1–6) for multiscale entropy (MSE)	100 Hz – Axivity AX3 triaxial accelerometer placed at L5	m=2, r=0.2, U=not reported, N=entire walking epoch	Low-pass Butterworth filter (20 Hz cutoff)	MSE was lower in CNLBP in the mediolateral direction (Y-axis), indicating an increase in regularity of trunk acceleration in daily living (τ ≥ 2) and in the laboratory environment (τ ≥ 4)
Oliosi et al. (2024, Portugal)	15-min windows across five consecutive days	Multiscale entropy (MSE) and SampEn	100 Hz – Smartphone accelerometer (Xiaomi Redmi Note 9) mounted on the chest using	m=4, r=not reported, N=long continuous time series (~5 hours per	Low-pass filter (10 Hz cutoff)	SampEn and MSE values in mediolateral (Y-axis) and anterior-posterior directions (X-axis) trunk acceleration did not show statistical significance differences.

		(SaEn) computed for different time scales	a harness	day)		
Shokouhyan et al. (2020, Iran)	30 s per trial (8 trials per participant)	Not reported	100 Hz – Vicon motion capture system with markers + force plate (Bertec, USA)	m=4, r=2.5% mean distance, U=not reported, N=full trial data	m=4, r=2.5% mean distance, U=not reported, N=full trial data	Entropy was higher in the CNLBP group, indicating lower regularity in trunk frontal angles (Y–axis) under proprioceptive perturbations.
Shokouhyan et al. (2022, Iran)	30 s per trial (8 trials per participant)	Not reported	100 Hz – Vicon motion capture system with markers + force plate (Bertec, USA)	m=4, r=2.5% mean distance, U=not reported, N=full trial data	Low-pass Butterworth filter (5 Hz cutoff)	Entropy was higher in the CNLBP group in the mediolateral direction (Y-axis), indicating increased regularity under proprioceptive perturbations (foam surface and vibration).

CLBP – Chronic Low Back Pain; CNLBP – Chronic Non-Specific Low Back Pain; IMU – Inertial Measurement Unit; MSE – Multiscale Entropy; SampEn – Sample Entropy; SaEn – Sample Entropy; SD – Standard Deviation; τ-values – Time Scale Factors for MSE; U – Length time series; N – Number of Data Points.

Critical appraisal checklist for analytical cross-sectional studies

The risk of bias assessment revealed methodological variability across the included studies. All studies presented clearly defined inclusion criteria, indicating a low risk of selection bias. Regarding the description of participants and study environment, Oliosi et al. (2024) provided only partial details, leading to some uncertainty about sample characteristics and study conditions. Bauer et al. (2017) partially met the criterion for the validity and reliability of exposure measurement, introducing a moderate risk of bias. Oliosi et al. (2024) did not meet this criterion, presenting a high risk of bias due to insufficient methodological details. Regarding objective and standardized criteria for measuring the condition, Oliosi et al. (2024) did not report the use of standardized protocols, contributing to a high risk of bias. When evaluating the identification of confounding factors, Bauer et al. (2017) and Shokouhyan et al. (2020) only partially addressed this issue, leading to a moderate risk of bias, while Oliosi et al. (2024) did not explicitly report confounding variables, increasing the risk of bias in this domain. Similarly, in terms of strategies to control for confounding factors, Bauer et al. (2017) and Shokouhyan et al. (2020) only partially addressed this issue, while Oliosi et al. (2024) did not mention any confounding control strategies, further increasing the risk of bias.

For the validity and reliability of the outcome measurement, Oliosi et al. (2024) partially met this criterion, raising concerns about data consistency. All studies applied appropriate statistical analyses, ensuring a low risk of bias in this domain.

Overall, Nishi et al. (2021) and Shokouhyan et al. (2022) were classified as having a low risk of bias, Bauer et al. (2017) and Shokouhyan et al. (2020) as having a moderate risk of bias, mainly due to limitations in confounding control, and Oliosi et al. (2024) as having a high risk of bias, particularly in exposure measurement, condition standardization, and confounding control.

Table 4 – Results of the risk of bias of the included studies.

Criteria	Bauer et al. (2017)	Nishi et al. (2021)	Oliosi et al. (2024)	Shokouhyan et al. (2020)	Shokouhyan et al. (2022)
1. Clearly defined inclusion criteria?	Yes	Yes	Yes	Yes	Yes
2. Detailed description of participants and setting?	Yes	Yes	Partial	Yes	Yes
3. Exposure measured in a valid and reliable way?	Partial	Yes	No	Yes	Yes
4. Objective and standardized criteria for measuring the condition?	Yes	Yes	No	Yes	Yes
5. Confounding factors identified?	Partial	Yes	No	Partial	Yes
6. Were strategies for dealing with confounding factors mentioned?	Partial	Yes	No	Partial	Yes
7. Were outcomes measured validly and reliably?	Yes	Yes	Partial	Yes	Yes
8. Was appropriate statistical analysis used?	Yes	Yes	Yes	Yes	Yes
General Risk of Bias	Moderate	Low	High	Moderate	Low

Yes = Criterion met, low risk of bias; Partial = Some uncertainty, possible moderate bias; No = Criterion not met, high risk of bias; Low = Low overall risk of bias. Moderate = Some methodological concerns; High = Greater potential for bias, less reliable results.

Discusion

The current systematic review investigated the use of entropy-based metrics to assess trunk movement regularity in individuals with CNLBP in analytical cross-sectional studies. The findings indicate task-dependent alterations in movement regularity, with significantly reduced entropy (increased movement regularity) observed in postural and gait tasks, while significantly increased entropy (reduced movement regularity) was found in flexion-extension movements.

According to Stergiou et al. (2011) (23) healthy biological systems exhibit optimal variability, characterized by a structured, non-random pattern that enables adaptation to task demands. This variability follows a structured, chaotic pattern rather than purely random noise. When this structured variability is lost, movement patterns become either excessively rigid or too disordered, reducing adaptability. This behavior is particularly relevant in chronic pain conditions, such as CNLBP, where an altered movement structure shifts towards a constrained, less adaptable neuromuscular state. Healthy biological systems maintain their adaptability through complex, dynamic interactions among multiple subsystems. Aging and the presence of pathological conditions disrupt these interactions, reducing overall system capability and limiting the ability of the individual to adapt to perturbations. In CNLBP, this manifests as a decline in movement flexibility, with reduced entropy in postural and gait tasks reflecting impaired adaptability. In contrast, increased entropy in flexion-extension tasks may indicate compensatory strategies. Together, these frameworks provide a theoretical explanation for the movement alterations observed in CNLBP, reinforcing the clinical relevance of entropy-based metrics for assessing neuromuscular health.

In the current review, the significantly reduced entropy (high movement regularity) reported in postural and gait tasks suggests that CNLBP individuals adopt more regular movement patterns, possibly to minimize discomfort or compensate for reduced movement stability. However, an increase in entropy (decreased movement regularity) observed in flexion-extension movements may indicate a decreased capacity of these individuals to deal with the demands of the task. In postural and gait tasks, reduced entropy values suggest increased movement regularity, which could indicate compensatory rigidity aimed at maintaining stability (19,22). In contrast, increased entropy values in repetitive flexion-extension movements may represent difficulty in establishing compensatory mechanisms to deal with the load applied, due to a reduced capacity of the neuromuscular system (25). These findings align with the pain adaptation model, which suggests that chronic pain alters motor control strategies, prioritizing protective mechanisms over movement efficiency (23). Furthermore, the findings highlight the importance of task-specific analyses when investigating movement in CNLBP, as biomechanical and neurological constraints influence movement variability.

Entropy measures, such as SampEn and MSE, have become a key tool in motor control research. Tang et al. (26) reviewed non-linear time-series analyses and emphasized entropy as a crucial parameter for quantifying movement adaptability. Similarly, Bisi & Stagni (27) explored the evolution of movement structure across different ages and task demands, demonstrating that entropy-based metrics effectively capture neuromuscular changes. The findings support that entropy alterations in CNLBP may represent a maladaptive shift in typical motor control mechanisms, particularly in response to pain or a lack of movement stability. Additionally, Yin et al. (28) introduced Multiscale Joint Permutation Entropy (MJPE) to evaluate temporal synchronization in movement patterns, which may provide further insights into motor coordination impairments in CNLBP. One of the main challenges in entropy-based studies is the lack of standardization in entropy computation, with regularity in parameters such as (i) embedding dimension (m): 2–3; (ii) tolerance (r): 0.15–0.2; (iii) number of scales in MSE: 5–10; and (iv) sampling frequencies: 50 Hz to 500 Hz. These inconsistencies complicate direct comparisons between studies and the translation of findings into clinical practice.

The current review presents some methodological limitations that should be considered when interpreting the findings. The heterogeneity in study designs, entropy computation methods, and motor tasks assessed limited direct comparisons across studies. Due to methodological heterogeneity, entropy values from different studies were analyzed qualitatively rather than pooled quantitatively, to ensure comparison consistency. The variation in entropy computation parameters, motor tasks, and sensor placements prevented the application of a meta-analytic approach, limiting the ability to quantify the magnitude of group differences. This review focused on identifying general trends rather than directly comparing absolute entropy values across studies to mitigate this limitation. Additionally, not all studies explicitly controlled potential confounding factors, such as pain intensity, physical activity level, previous treatments, and comorbidities. Since these factors can influence movement regularity, their lack of consideration may introduce variability in the reported findings. This limitation should be acknowledged when interpreting the results. While chronic pain appears to play a central role in motor control alterations, uncontrolled variables such as activity level and comorbidities may also influence movement regularity patterns.

From a scientific standpoint, non-linear metrics are gaining recognition in movement research, particularly for assessing movement adaptability and motor control dysfunctions. While the findings of the current review reinforce the utility of entropy metrics in characterizing motor control in individuals with CNLBP, their clinical application still presents challenges. The absence of reference values and cutoff points to distinguish between healthy individuals and those with CNLBP hinders translation of these results into clinical practice. Moreover, differences in data collection and analysis protocols may impact the interpretation of entropy indices across different contexts. This analysis is more adequate for repeated-measures studies or to quantify changes over time. Future studies should explore the development of standardized guidelines for the clinical use of entropy as an objective biomarker of motor dysfunction, as well as its relationship with functional outcomes and pain perception in CNLBP patients.

Conclusion

This review demonstrates that movement regularity in CNLBP is task-dependent. Reduced entropy (i.e., increased regularity) was observed in postural and gait tasks, while flexion-extension tasks showed increased entropy. These findings underscore the relevance of entropy-based metrics for identifying motor control deficits and reinforce the importance of task-specific evaluation strategies in clinical settings.

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3. CONSIDERAÇÕES FINAIS

Este trabalho reuniu e analisou criticamente os achados de estudos transversais que utilizaram métricas de entropia para avaliar a regularidade do movimento do tronco em indivíduos com dor lombar crônica inespecífica (DLCI), em comparação com controles saudáveis. Os resultados demonstraram que a DLCI está associada a alterações no controle motor, com padrões de regularidade que variam conforme a tarefa executada.

A entropia, como métrica de complexidade, revelou-se sensível para detectar essas variações, evidenciando maior regularidade (menor entropia) em tarefas posturais e de marcha, e menor regularidade (maior entropia) em movimentos dinâmicos como a flexo-extensão.

Esses resultados sustentam a hipótese de que a DLCI compromete a adaptabilidade do sistema motor, conforme previsto pelos modelos de sistemas dinâmicos não lineares, nos quais a variabilidade estruturada representa um indicador de saúde e flexibilidade funcional. A rigidez excessiva ou a desorganização motora observadas nos estudos refletem possíveis estratégias compensatórias ou disfunções no controle neuromuscular.

A análise realizada revelou importantes limitações metodológicas nos estudos incluídos. Houve grande heterogeneidade quanto aos protocolos de coleta de dados, parâmetros utilizados no cálculo da entropia (como dimensão de incorporação, tolerância e número de escalas tipo de tarefa avaliada). Essa variabilidade impede comparações diretas entre os estudos e limita a extrapolação clínica dos resultados

Apesar dessas limitações, esta revisão sistemática oferece uma importante contribuição ao consolidar o conhecimento atual sobre o uso da entropia na análise do movimento em indivíduos com DLCI. Os resultados reforçam a relevância de abordagens baseadas na complexidade para avaliação do controle motor e sugerem que medidas de entropia podem se tornar ferramentas úteis na prática clínica e na pesquisa aplicada em fisioterapia.

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5. IMPACTOS PRÁTICOS DOS ACHADOS PARA SOCIEDADE

Os resultados desta dissertação reforçam o potencial das métricas de entropia como ferramentas para a avaliação do controle motor em indivíduos com dor lombar crônica inespecífica (DLCI). No contexto clínico, a identificação de padrões alterados de regularidade do movimento pode oferecer subsídios objetivos para a caracterização funcional de pacientes, contribuindo para um raciocínio clínico mais refinado e personalizado.

A detecção de maior rigidez motora em tarefas posturais e de marcha, ou de desorganização em tarefas dinâmicas, pode orientar intervenções fisioterapêuticas mais precisas. Além disso, a aplicabilidade de sensores acessíveis, como acelerômetros portáteis e dispositivos móveis, abre perspectivas para a incorporação de métricas de complexidade em ambientes clínicos, facilitando o monitoramento do progresso terapêutico.

Do ponto de vista científico, os achados destacam a necessidade de padronização dos protocolos de coleta e análise de entropia, o que permitiria maior comparabilidade entre estudos e viabilizaria a construção de valores de referência para diferentes populações.

6. APÊNDICES

Database Search Strategies

PubMed (via NCBI)

("low back pain"[Title/Abstract] OR "lumbar pain"[Title/Abstract] OR "chronic low back pain"[Title/Abstract])
AND ("regularity"[Title/Abstract] OR "entropy"[Title/Abstract] OR "approximate entropy"[Title/Abstract]
OR "SampEn"[Title/Abstract] OR "MSEentropy"[Title/Abstract] OR "complexity"[Title/Abstract])
AND ("movement"[Title/Abstract] OR "motor task"[Title/Abstract] OR "trunk movement"[Title/Abstract])
Applied Filters: No language or date filters.

Web of Science (All Bases)

TS=("low back pain" OR "lumbar pain" OR "chronic low back pain")
AND TS=("regularity" OR "entropy" OR "approximate entropy" OR "SampEn" OR "MSEentropy" OR "complexity")
AND TS=("movement" OR "motor task" OR "trunk movement")

Filters Applied: Results are manually reviewed to avoid duplications.

EBSCOhost (CINAHL, SPORTDiscus)

(low back pain OR lumbar pain OR chronic low back pain)
AND (regularity OR entropy OR ApEnOR OR MSEentropy OR complexity)
AND (movement OR motor task OR trunk movement)
Applied Filters: Selection is limited to original articles.

Scopus

("low back pain" OR "lumbar pain" OR "chronic low back pain")
AND("regularity" OR "entropy" OR "approximate entropy" OR "SampEn" OR "MSEentropy" OR "complexity")
AND("movement" OR "motor task" OR "trunk movement")
Applied Filters: Exclusion of conference abstracts and systematic reviews.

LILACS (via VHL)

"low back pain" OR "lumbar pain" OR "chronic low back pain"
AND "regularity" OR "entropy" OR "approximate entropy" OR "SampEn" OR "MSEentropy" OR "complexity"
AND "movement" OR "motor task" OR "trunk movement"

EMBASE

('low back pain': ti, ab OR 'lumbar pain': ti, ab OR 'chronic low back pain': ti, ab)
AND ('regularity': ti, ab OR 'entropy': ti, ab OR 'approximate entropy': ti, ab
OR 'SampEn': ti, ab OR 'MSEentropy': ti, ab OR 'complexity': ti, ab)
AND ('movement': ti, ab OR 'motor task': ti, ab OR 'trunk movement': ti, ab)

Applied Filters: Original articles only; exclusion of case studies and systematic reviews.These methodological differences underscore the need for standardization in entropy analysis for CNLBP research. Future studies should harmonize data collection protocols, particularly in recording duration, entropy computation parameters, and filtering methods, to facilitate comparability and reproducibility across investigations. Additionally, adopting smartphone-based motion analysis tools (Oliosi et al., 2024) highlights a promising avenue for real-world movement regularity assessments, bridging the gap between laboratory-based and ecological motor control evaluations in CNLBP populations.

Overall, the findings support using entropy metrics in evaluating motor control deficits in CNLBP. However, the regularity in tasks and entropy computation methodologies suggests the need for standardized protocols to enhance the comparability of results across studies. The selection of the ML-axis for most analyses underscores its clinical relevance in assessing dynamic postural control and stability impairments in individuals with chronic low back pain.

In summary, the meta-analysis confirms that entropy-based measures effectively differentiate CNLBP patients from controls, particularly in postural and dynamic movement tasks. The findings emphasize the clinical relevance of assessing mediolateral movement regularity and highlight the need for tailored interventions targeting postural control impairments in chronic low back pain populations.

Future Research Directions

To reduce bias and improve study comparability, future research should:

Standardize entropy computation methodologies to minimize statistical inconsistencies.

Report non-respondents and sample size calculations to enhance transparency.

Use blinded outcome assessments and adjust for confounders, ensuring stronger causal inferences in entropy-based CNLBP analyses.

7. PRODUTOS EDUCACIONAIS, CIENTIFÍCOS, SOCIOCULTURAUS E TECNOLÓGICOS/ECONÔMICOS DESENVOLVIDOS NO PERÍODO DO MESTRADO.

1. Simpósio Multidisciplinar de Inovação Tecnológica do Ecossistema de Saúde do Distrito Federal (SIMTEC-Saúde-2023

Impacto científico

Detalhamento do tipo de produto/atividade: Comissão Organizadora.

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Docente do PPGCR envolvido: Prof° Dr° Wagner Rodrigues Martins e Profª Drª Elaine Cristina Leite Pereira