

LITERATURE REVIEW

Measuring Lumbar Reposition Accuracy in Patients With Unspecific Low Back Pain

Systematic Review and Meta-analysis

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Study Design. Systematic review and meta-analysis.

Objective. To evaluate if patients with nonspecific chronic low back pain (NSCLBP) show a greater lumbar reposition error (RE) than healthy controls.

Summary of Background Data. Studies on lumbar RE in patients with NSCLBP present conflicting results.

Methods. A systematic review and meta-analysis of the available literature were performed to evaluate differences in RE between patients with NSCLBP and healthy controls. Data on absolute error, constant error (CE), and variable error were extracted and effect sizes (ESs) were calculated. For the CE flexion pattern and active extension pattern, subgroups of patients with NSCLBP were analyzed. Results of homogeneous studies were pooled. Measurement protocols and study outcomes were compared. The quality of reporting and the authors' appraisal of risk of bias were investigated.

Results. The original search revealed 178 records of which 13 fulfilled the inclusion criteria. The majority of studies showed that patients with NSCLBP produced a significantly larger absolute error (ES, 0.81; 95% confidence interval [95% CI], 0.13–1.49) and variable error (ES, 0.57; 95% CI, 0.05–1.09) compared with controls. CE is direction specific in flexion and active extension pattern subgroups of patients with NSCLBP (ES, 0.39; 95% CI, −1.09 to 0.3) and ES, 0.18; 95% CI, −0.3 to 0.65, respectively). The quality of reporting and the authors' appraisal of risk of bias varied considerably. The applied test procedures and instrumentation

varied between the studies, which hampered the comparability of studies.

Conclusion. Although patients with NSCLBP seemed to produce a larger lumbar RE compared with healthy controls, study limitations render firm conclusions unsafe. Future studies should pay closer attention to power, precision, and reliability of the measurement approach, definition of outcome measures, and patient selection. We recommend a large, well-powered, prospective randomized control study that uses a standardized measurement approach and definitions for absolute error, CE, and variable error to address the hypothesis that proprioception may be impaired with CLBP.

Key words: low back pain, proprioception, spine, posture, review, meta-analysis, lumbar reposition error, lumbosacral region, lumbar spine, motor control, movement control.

Level of Evidence: 1

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Low back pain (LBP) affects up to 84% of people in industrialized countries.¹ In 2005, the total direct costs of LBP in Switzerland amounted to €2.6 billion.² Evidence recommends the use of a prognostic subclassification including cognitive, physical, and lifestyle factors for all patients with chronic LBP (CLBP) who do not display underlying red flag disorders; specific pathoanatomical disorders or pain disorders driven from the forebrain with a dominance of nonorganic factors.^{3–7} The physical factor of this classification system includes a large subgroup of patients with maladaptive movement or control disorders.^{3–6} Movement and control disorders are interpreted as maladaptive primary physical compensations, after an initial painful episode, which drive the CLBP state.³ They presumably lead to a proprioceptive deficit, because of stress on local muscle spindles and joint receptors in the painful area resulting from stress to a joint caused by an individual's maladaptive movement.³ Proprioceptive deficits may lead to altered central sensory-motor control mechanisms and disrupted body schema. Subsequently, abnormal joint and tissue loading during daily activities and postures may affect local proprioceptors and maintain this vicious circle.^{7–13} Reposition error (RE) is regarded as a

measure reflecting proprioception deficits in the lower spine and typically involves participants trying to reproduce a specific target body position.^{14–16}

RE can be expressed as absolute error (AE), constant error (CE), or variable error (VE). AE represents the error magnitude and is defined as the absolute difference between the target lumbar angle and actual lumbar angle. CE represents the error magnitude direction such that CE indicates bias toward a particular direction where negative CE typically represents a bias in the undershooting direction. VE describes the variability of the subjects' performance equivalent to the standard deviation of RE. High VE values reflect high variability in repositioning.¹⁷

Using lumbar RE as an outcome measure, several studies have investigated deficits in proprioception in patients with LBP.^{11,12,14–25} In these tests, patients are asked to reproduce a specific (e.g., neutral) lumbar position after performing an active or passive movement. Some studies reported an increased lumbar RE of patients with LBP compared with a healthy population.^{12,14–16,18,22,23} Classifying patients with non-specific CLBP (NSCLBP) based on movement and control impairments³ revealed direction-specific differences in lumbar RE between flexion pattern (FP) and active extension pattern (AEP) subgroups of patients with NSCLBP.^{14,16} A recent randomized controlled trial showed that these lumbar spine position sense deficits were treatable with a classification-guided postural intervention.²⁶ However, other studies have shown no differences between patients with LBP and healthy controls when testing for lumbar position sense,^{17,19,21} even after they were subgrouped according to a McKenzie classification system or *International Classification of Diseases, Tenth Revision* codes.¹⁷

It is discussed controversial if proprioception is altered in patients with NSLBP that display physical factors. Therefore a meta-analysis of the earlier results is advisable and a systematic review may contribute to a better understanding of this issue.

Measurement procedures for assessing RE and findings vary among studies in patients with LBP and healthy controls. Therefore, the aim of this systematic review and meta-analysis was to evaluate if patients with NSCLBP produce a greater lumbar RE. Thus, a statistical pooling of homogeneous study results was performed. Furthermore, design and measurement methods of RE studies were compared with state recommendations for further research.

MATERIALS AND METHODS

Data Sources and Searches

Study identification commenced by electronic searching, using the MEDLINE (through PubMed), CINAHL, and Cochrane Library, on articles published between January 1, 1990 and September 30, 2013. Search terms used were low back pain, proprioception, position sense, kinesthesia, reposition, and repositioning. Both Medical Subject Headings terms and free text words were entered. A combination of these terms was used to extract a comprehensive list of articles, from which the

titles and abstracts were screened for eligibility. An additional search for gray literature on issue-specific databases,^{27–29} citation tracking, and key author searches was conducted.

Eligibility Criteria

The following criteria were applied to determine the eligibility of each study for inclusion in the meta-analysis:

- Patients with NSCLBP and healthy controls.
- At least 1 measure reflecting RE (AE, CE, and VE).
- Published in English or German.

Two reviewers independently evaluated records for eligibility. Disagreement was resolved by discussion and consensus. To avoid duplication in pooling, data were included only once if they were reported in previously published work.

Quality Assessment

Two reviewers independently analyzed the quality of the included studies as recommended by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration.^{30,31} Accordingly, the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) statement was used to analyze both the quality of reporting and the author's "appraisal of risk of bias."^{32,33} Discrepancies were solved by consensus. Results were summarized in tabular form to enable a sensitivity analysis based on quality criteria.

Data Analysis

Two reviewers independently extracted information of each study including the setting of the study, characteristics of patients, inclusion and exclusion criteria, instrumentation, test protocol, and outcomes (tasks and variables). Those data were presented narratively in tabular form. Data on reliability and measurement error of the test protocols were extracted and presented in tabular form.

Descriptive data for continuous variables were expressed as mean and standard deviation. The Cochrane Collaboration's Revman 5.2.7 software was used for a pooled data analysis. Data were reported as AE, CE, or VE. Effect sizes (ESs) of single studies were expressed as Hedges g or Cohen r , if the original data were non-normally distributed, with 95% confidence intervals. Those studies describing results reflecting AE, CE, and VE evaluated with neutral-slumped-neutral sitting were used for meta-analysis using a random-effects model, subgrouped for adults and adolescents. Neutral-slumped-neutral sitting was chosen as pooling criteria because 6 studies used this setup. All other setups were used once. In addition, CE was analyzed independently for FP and AEP subgroups of NSCLBP because CE is direction specific in these subgroups.^{14–16} As the definition of undershooting into a flexed position and overshooting into an extended position varied between the studies, we applied a common definition and changed the sign of study results in 1 study¹⁶ according to this definition. Undershooting into a flexed position was

given a negative sign, whereas overshooting into an extended position was given a positive sign. To assess heterogeneity, the Q statistic and its P value were calculated. I^2 was calculated as a measure of between-study heterogeneity (for each set of effect sizes [EFs]) according to Borenstein.³⁴ The meta-analyses were first performed including all studies fulfilling the criteria mentioned in the earlier text. As a sensitivity analysis, the meta-analysis were then repeated by excluding studies with poor quality of reporting and studies appearing as outliers to assess their influence on the meta-analysis.

RESULTS

The search revealed 178 records; 31 of them were screened in full text (Figure 1). Eighteen studies were excluded because of study design (*e.g.*, interventional studies, no healthy control group), outcome variables (no AE, CE, VE), or the character of included subjects (no NSCLBP). A total of 13 studies^{11,12,14–25} fulfilled the inclusion criteria (Table 1). Four of 13 of the included studies did not provide sufficient data on RE (mean, standard deviation).^{17,20–22} Upon contacting the corresponding authors, we did not receive this information

from them. The overall loss of subjects was 148 patients with NSCLBP and 86 controls.

Table 2 summarizes the applied test procedures and instrumentation, which varied largely between the studies. Table 3 shows the reported variables and calculated EFs. The majority of the studies showed that patients with NSCLBP produced a significantly larger AE and VE compared with controls. The quality of reporting and the authors' appraisal of risk of bias (STROBE) varied considerably. Some studies do not present information on risk of bias and attempts to reduce bias (Table 4). Reporting on reliability and measurement error was inconsistent with studies not reporting either or referring to measurement error and reliability of the measurement device (Table 5).^{12,15,18,19}

Six studies were included in the meta-analysis as they shared the same measurement protocol (neutral-slumped-neutral in sitting) (Figure 2). The studies were subgrouped, according to the age of the participants, into adults^{12,15,16,24,25} and adolescents.¹⁴

The overall EF of 0.81 (95% confidence interval [95% CI], 0.13–1.49) illustrates that patients with LBP produce a

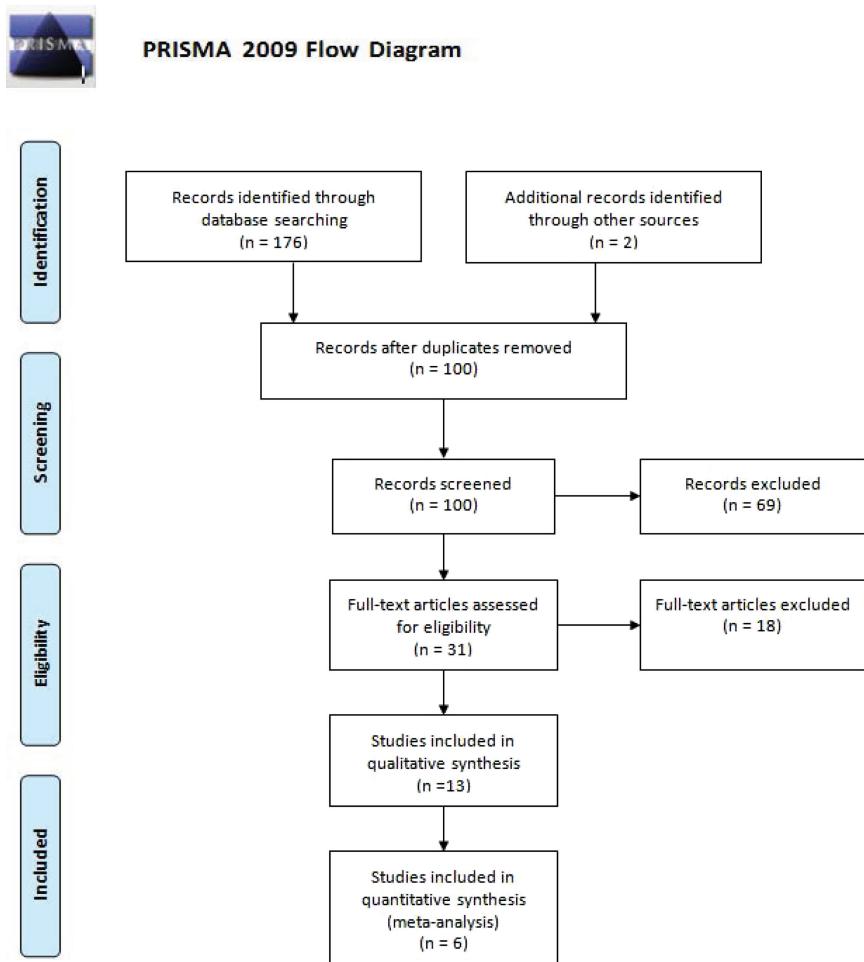


Figure 1. Flow chart according to PRISMA. PRISMA indicates preferred reporting items for systematic reviews and meta-analyses.

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Med* 6(6): e1000097. doi:10.1371/journal.pmed.1000097

For more information, visit www.prisma-statement.org.

TABLE 1. Study Design and Subjects

Origin Study	NSCLBP			Criteria			Healthy Controls		
	n	M/F	Age (yr)	Inclusion	Exclusion	N	M/F	Age (yr)	Matching
O'Sullivan et al ⁵	15	10/5	31.3 ± 10.3	NSCLBP >3 mo, 18–65 yr, increasing symptoms during prolonged sitting, reduced symptoms during standing and walking	Previous back surgery, neurological symptoms, ear/visual disturbance, red flags, pregnancy/<6 mo postpartum	15	10/5	32.1 ± 9.2	Age, sex, BMI
Astfalck et al ¹⁴	28	14/14	15.7 ± 0.5	NSCLBP >3 mo, 14–16 yr, BMI < 28 kg/m ² , mechanically induced pain in area between T12 to gluteal folds, no peripheral pain referral, moderate ongoing LBP (NRS >3, most days of the week)	Specific diagnosis, previous back surgery, neurological symptoms, pelvic or abdominal pain, lower limb surgery/ current injury, pregnancy/<6 mo postpartum, not English speaking, inability to assume test posture	28	14/14	15.4 ± 0.5	Age, sex, pubertal stage, socioeconomic status
Sheeran et al ¹⁶	90	31/59	35 ± 10.9	LBP >3 mo, mechanical basis of disorder, motor control impairment (flexion/active extension pattern)	Red flags, yellow flags, pregnancy/breastfeeding, previous back surgery, ear/vestibular/neurological dysfunction affecting balance, not able to sit or stand up from a stool unaided	35	13/22	36.0 ± 10.3	...
Georgy ¹⁸	15	?	40.1 ± 6.1	LBP >3 mo, mechanical dysfunction, NRS >5, lumbar ROM of at least 50% of normal range	Previous inner ear infection or vestibular disorder with balance disturbance, history of head trauma with residual neurological deficits, metabolic diseases, pregnancy/breastfeeding, spinal surgery, severe back pain	15	?	38.5 ± 5.9	...
Asell et al ¹⁷	92	45/47	38 ± 7	LBP >6 mo	Diabetes, psychiatric diagnoses, neurological and rheumatic disorders, dizziness, vestibular disease, surgery last 3 mo	31	16/15	36 ± 9	Age, sex
Descarreaux et al ²⁰	16	11/5	41.1	NSLBP >6 mo	Spondylolisthesis, spondylolysis, ankylosis spondylitis, osteoarthritis, inflammatory arthritis, nerve root compression, trunk neuromuscular disease, scoliosis (>15°), previous spinal surgery, malignant tumor, hypertension, pregnancy/breastfeeding	15	9/6	38.2	...
O'Sullivan et al ²	15	6/9	38.8 ± 12	Recurrent LBP >3 mo, diagnosis of lumbar segmental instability flexion pattern	Neurological involvement, recent back surgery, pain preventing the test, recent motor control rehabilitation, ear/visual disturbance, severe soft-tissue tightness around hip/trunk	15	6/9	38.2 ± 10.9	Age, height, weight
Koumantakis et al ⁹	62	30/32	38.2 ± 10.7	Recurrent mechanical NSCLBP with at least 2 episodes within the past year with pain duration of less than half the days in the past year, still working, no neurological condition	Trunk or lower limb pathology, deformity, or condition that may affect motor control	18	8/10	24.6 ± 4.0	...

(Continued)

TABLE 1. (Continued)

Origin Study	NSCLBP			Criteria			Healthy Controls		
	n	M/F	Age (yr)	Inclusion	Exclusion	N	M/F	Age (yr)	Matching
Brumagne et al ¹	23	7/16	21.8 ± 2.1	Mechanical NSCLBP	Recent history of inner ear infection with associated balance or coordination problem, history of cerebral trauma with unresolved neurosensory symptoms, vestibular disorder, previous spinal surgery, specific balance or stabilization training in the last 6 mo, pain medication	21	6/15	22.3 ± 3.8	...
Newcomer et al ²	20	8/12	39.3 ± 11.4	NSCLBP (mechanical, nonradicular) ≥3 mo, ROM of at least 50% of normal value	Severe pain preventing cooperation with the study, pregnancy and lactation, previous back surgery, current lower extremity problems, radiculopathy, vertebral compression fracture, neurological deficit, symptoms of vertigo or dizziness	20	7/13	39.1 ± 11.3	...
Newcomer et al ²	20	9/11	44.2 ± 10.6	Pain between L1 and the gluteal folds ≥6 mo, average pain level of 5 of 10 in the preceding week, ROM of at least 50% of normal value	Severe pain preventing cooperation with the study, pregnancy and lactation, previous back surgery, scoliotic curvature greater than 15°, neurological or current lower extremity problems, lumbar radiculopathy, vertebral compression fracture, symptoms of vertigo or dizziness	20	9/11	39.8 ± 12.7	...
Lam et al ²⁴ and Maffey Ward et al ²⁵	20	11/9	29 ± 5	Mechanical back pain ≥3 mo	Back pain from a nonmusculoskeletal pathology, neurological involvement, previous surgery in back/abdomen/chest	10	5/5	23	...
Gill and Callaghan ²³	20	7/13	43.3	Chronic mechanical LBP >12 mo	Neurological deficit, psychological component, further medical problems, nerve root pain	20	7/13	32.9	Sex

NSCLBP indicates nonspecific chronic low back pain; LBP, low back pain; n, number of patients; M/F, male/female; BMI, body mass index; ROM, range of motion.; ?, not described by the authors

TABLE 2. Test Procedure and Instrumentation

TABLE 2. Test Procedure and Instrumentation				
Study	Movement Task	Measurement Details	Eyes Open/ Eyes Closed	Instrument, Sensor Position
O'Sullivan et al ¹⁵	P: Sitting, warming up by performing max trunk flexion/extension, 1 practice trial IP: Sitting (90° hips, knees, ankles), arms supinated on thighs, neutral lumbopelvic spinal posture, (maintained 5 s) M: Slumped position (maintained 5 s) TP: Initial position (maintained 5 s)	n: 3 Rest (s): ? Feedback*: undergarments, shorts Feedback†: no	...	I: Body Guard (Sels Instruments, Vorselaar, Belgium) SP: L3, S2
Astafalck et al ¹⁴	P: Sitting, 3 × ROM, 2 practice trials IP: Sitting (90° hips and knees), arms supinated on thighs, midrange sitting posture position (maintained 5 s) M: Slumped position (maintained 5 s) TP: Initial position	n: 3 Rest (s): ? Feedback*: undergarments, shorts Feedback†: no	EC	I: Fastrak (Polhemus Navigation Sciences Division, Colchester, VT) SP: L3, S2
Sheeran et al ¹⁶	P: Sitting/standing, 3 × ROM IP: (1) Sitting, arms loose on thigh; (2) standing, feet shoulder-width apart, neutral lumbar and thoracic midrange position (maintained 5 s) M: (1) Relaxed usual sitting (maintained 5 s); (2) relaxed usual standing TP: Initial position	n: 4 Rest (s): ? Feedback*: loose clothing Feedback†: no	EC	I: Vicon Motion Systems Ltd., Oxford, England SP: T12, S1
Georgy ¹⁸	P: Sitting, stabilized by straps, 3 practical trials IP: Sitting, passively moved to 30° of lumbar flexion (maintained 10 s) M: Upright neutral sitting TP: 30° lumbar flexion (maintained 3 s)	n: 3 Rest (s): 10 Feedback*: ? Feedback†: no	...	I: Biomedex System 3 Pro Isokinetic Dynamometer (Biomedex Medical Inc., Shirley, NY) SP: Axis of actuator arm with L5–S1
Asell et al ¹⁷	P: Sitting, 2 × sit-to-stand, 2 × ROM, 6 practical trials (3 verbally, 3 prerecorded instructions) IP: Sitting, hips, and knees at 90°, guarded to the target position (maintained 2 s) M: Lumbar flexion until auditory signal (90% of max flexion S2) TP: 1/3 of the way toward maximal extension from the subjects normal sitting position, verbal signal by subject	n: 10 Rest (s): 3 Feedback*: undergarments, hair in a bun, boldered armpits, No drinking or eating 2 hr prior to testing Feedback†: no	EC	I: Fastrak (Polhemus Navigation Sciences Division) SP: T7, S2, midpoint between those 2 segments
Descarreaux et al ¹⁰	P: Standing, max ROM, learning phase with visual accuracy feedback till 5 consecutive trunk positioning within 10% margin IP: Neutral (0° flexion or extension), pelvis and legs immobilized M: Flexion (15°, 30°, 60°), extension (15°), randomized TP: Flexion (15°, 30°, 60°), extension (15°), randomized	n: 10 (5 seconds each) Rest (s): ? Feedback†: no	...	I: Loredan (Loredan Biomedical, West Sacramento, CA) SP: ?
O'Sullivan et al ¹²	P: Sitting, 3 × ROM IP: Sitting (90° hips, knees, ankles), arms relaxed on thighs, neutral spine posture (maintained 5 s) M: Full lumbar flexion (maintained 5 s) TP: Initial position	n: 5 Rest (s): ? Feedback*: undergarments, shorts Feedback†: no	EC	I: Fastrak (Polhemus Navigation Sciences Division) SP: T12, L2, L4, S2

(Continued)

TABLE 2. (Continued)

Study	Movement Task	Measurement Details	Eyes Open/ Eyes Closed	Instrument, Sensor Position
Koumantakis et al ⁹	P: Standing, practicing with visual feedback IP: Standing, hip leaning against a bench M: Flexion, rotation, side-flexion TP: 20° Flexion, 15° rotation, 15° side-flexion	n: 3 within 30 s Rest (s): ? Feedback*: loose clothing, barefoot/flat shoes Feedback†: no	EC	I: Lumbar Motion Monitor (LMM, Chattecx Corp., Chattanooga, TN) SP: ?
Brumagne et al ¹¹	P: Standing, 10 × pelvic tilt to warm-up, ROM pelvic tilt IP: Criterion position varying around neutral (maintained 5 s) M: Anterior pelvic tilt TP: Criterion position	n: 5 Rest (s): ? Feedback*: shorts Feedback†: no	I: Electrogoniometer SP: ?
Newcomer et al ²¹	P: Standing IP: Standing, feet at shoulder-width apart and arms at side, (1) neutral; (2) 50% max ROM of flexion, extension, rotation, side-flexion M: (1) Flexion, extension, rotation, side-flexion; (2) to neutral TP: (1) Neutral position (5 s to move to desired position, maintained 2 s) (2) 50% of max ROM of flexion, extension, rotation, lateral-flexion (5 s to move to desired position, maintained 2 s)	n: 3 Rest (s): 2 Feedback: ?	EO/EC	I: Fastrak (Polhemus Navigation Sciences Division) SP: L1, S1
Newcomer et al ²²	P: Standing, feet shoulder-width apart, arms at side, lower extremity and pelvic immobilized, ROM IP: Standing, feet shoulder-width apart, arms at side, lower extremity and pelvic immobilized, neutral M: Flexion, extension, side-flexion (5 s to move to desired position) TP: 30%, 60%, 90% of max ROM (maintained for 2 s)	? ...	EC	I: Fastrak (Polhemus Navigation Sciences Division) SP: T1, S1
Lam et al ⁴ and Maffey-Ward et al ⁵	P: Cycling (5 min), ROM, 5 practice trials IP: Sitting with hips and knees 90°, neutral upright posture M: Full lumbar flexion (maintained 3 s) TP: Initial position	n: 3 Rest (s): 15 Feedback: shorts, undergarments, no drinking or eating 2 hr prior testing	EC	I: Fastrak (Polhemus Navigation Sciences Division) SP: T10, S2
Gill and Callaghan ²³	P: 10 practical trials with visual feedback from screen IP: (1) Standing; arms crossed; (2) 4-point kneeling: 90° of hips, knees, shoulders M: Lumbar flexion TP: Lumbar flexion 20°	n: 10 within 30 s Rest (s): ? Feedback*: loose clothing	EC	I: Lumbar Motion Monitor (LMM, Chattecx Corp., Chattanooga, TN) SP: Harness, inferior binding posts level of T7

*Sensory feedback (clothing, organs). †Acoustic or verbal feedback during measurements.
S indicates seconds; EO/CE, eyes open/eyes closed; C, cervical; T, thoracic; S, sacral; max, maximal; ROM, range of motion; n, number of trials; SP, sensor position; I, instrument; P, preparation; IP, initial position; M, movement; TP, target position; ?, not described by the authors.

TABLE 3. Outcomes and Effect Size Measures

	Test Position	Movement Direction	Patients			Controls			Effect Size		
			Mean	SD	n	Mean	SD	n	Hedges g/ Cohen r*	95% CI LL	95% CI UL
Absolute error											
O'Sullivan et al ¹⁵	Sitting	Flexion	11.5	6.4	15	5.1	3.6	15	1.20	0.41	1.99
Astfalck et al ¹⁴	Sitting	Flexion	4.1	2.3	28	3.1	1.3	28	0.53	-0.01	1.06
Sheeran et al ¹⁶	Sitting	Flexion	7.7	4.1	90	1.8	0.8	35	1.67	1.23	2.11
Georgy ¹⁸	Sitting	Extension	7.5	3.3	15	2.8	0.9	15	1.88	1.04	2.72
O'Sullivan et al ¹²	Sitting	Flexion	1.7	0.8	15	1.1	0.6	15	0.83	0.08	1.58
Lam et al ²⁴ /Maffey-Ward et al ²⁵	Sitting	Flexion	2.3	0.9	20	2.6	1.2	10	-0.29	-1.05	0.47
Gill and Callaghan ²³	Standing	Flexion	6.7	5.0	20	4.5	3.4	20	0.26	-0.12	1.20
Sheeran et al ¹⁶	Standing	Flexion	6.3	3.7	90	1.9	1.3	35	1.67	1.23	2.11
Koumantakis et al ¹⁹	Standing	Flexion	5.5	3.5	62	3.7	1.8	18	0.55	0.03	1.08
Brumagne et al ¹¹	Standing	Extension	4.3	1	23	1.6	0.6	21	3.18	2.30	4.06
Constant error											
O'Sullivan et al ¹⁵	Sitting	Flexion	-6.9	11.5	15	2.6	5.0	15	-1.04	-1.79	-0.30
Astfalck et al ¹⁴	Sitting	Flexion	-0.1	4.2	28	-0.8	2.6	28	0.20	-0.32	0.72
Sheeran et al ¹⁶	Sitting	Flexion	0.9	7.7	90	0.2	1.1	35	0.11	-0.28	0.49
Brumagne et al ¹¹	Standing	Extension	-2.5	2.5	23	-0.6	1.0	21	-0.96	-1.58	-0.35
Sheeran et al ¹⁶	Standing	Flexion	-1.9	5.2	90	-0.5	0.9	35	-0.31	-0.70	0.08
Variable error											
O'Sullivan et al ¹⁵	Sitting	Flexion	4.3	2.4	15	3.6	2.9	15	0.25*	-0.44	0.95
Astfalck et al ¹⁴	Sitting	Flexion	3.1	2.1	28	2.8	1.6	28	0.16	-0.37	0.68
Sheeran et al ¹⁶	Sitting	Flexion	4.2	2.6	90	1.9	1.0	35	1.01	0.60	1.42
Koumantakis et al ¹⁹	Standing	Flexion	2.2	1.6	62	1.7	1.0	18	0.33	-0.19	0.86
Brumagne et al ¹¹	Standing	Extension	3.3	1.4	23	1.7	0.7	21	1.40	0.75	2.05
Sheeran et al ¹⁶	Standing	Flexion	4.2	2.4	90	1.8	1.2	35	1.12	0.70	1.53

*Data were non-normally distributed and Cohen r was calculated as effect size measure.
CI indicates confidence interval; LL, lower limit; UL, upper limit; SD, standard deviation.

TABLE 4. Study Quality Assessment Based on STROBE^{32,33}

STROBE ⁽³⁾	Study Item	Asell et al ¹⁷	Astfalck et al ¹⁴	Brumagne et al ¹¹	Descarreaux et al ²⁰	Gill and Callaghan ¹⁸	Georgy ¹⁸	Koumantakis et al ⁹	Lam et al ²⁴	Maffey-Ward et al ²⁵	Newcomer et al ²¹	O'Sullivan et al ¹⁵	O'Sullivan et al ¹²	Sheeran et al ¹⁶
Title and abstract	1a	1	0	1	1	1	1	1	1	0	0	0	0	1
Background	2	1	1	1	1	1	1	1	1	1	1	1	1	1
Objectives	3	1	1	1	1	1	1	1	1	1	1	1	1	1
Introduction														
Methods														
Study design	4	1	0	0	0	1	0	0	0	0	0	0	0	0
Setting	5	0	1	0	0	0	0	0	0	0	0	0	0	0
Participants	6a	1	1	1	1	1	1	1	1	1	1	1	1	1
	6b	1	1	0	0	0	0	0	0	0	0	0	0	1
Variables	7	1	1	0	1	0	0	1	1	0	0	1	1	0
Data sources	8	1	0	1	1	1	1	1	1	1	1	1	1	1
Bias	9	1	1	0	1	1	1	1	1	0	0	1	1	1
Study size	10	0	1	0	0	0	0	0	0	0	0	0	0	1
Quantitative variables	11	1	0	1	0	0	1	0	0	1	1	0	0	1
Statistical methods	12a	1	1	1	1	0	1	1	1	1	1	1	1	1
	12b	1	1	0	1	1	0	0	0	1	1	0	0	1
	12c	0	0	0	0	0	0	0	0	0	0	0	0	0
	12d	0	1	0	0	0	0	0	0	0	0	0	0	0
	12e	0	0	0	0	0	0	0	0	0	0	0	0	0
Results														
Participants	13a	0	1	0	1	0	0	0	0	0	0	0	0	1
	13b	0	1	0	0	0	0	0	0	0	0	0	0	0
	13c	0	1	0	0	0	0	0	0	0	0	0	0	0
Descriptive data	14a	1	1	1	1	0	1	0	0	1	1	1	1	1
	14b	0	0	0	0	0	0	0	0	0	0	0	0	0

(Continued)

TABLE 4. (Continued)

STROBE ⁽³⁾	Study Item	Asell et al ¹⁷	Astfalck et al ¹⁴	Brumagne et al ¹¹	Descarreaux et al ²⁰	Gill and Callaghan ¹⁸	Georgy ¹⁸	Koumantakis et al ⁹	Lam et al ²⁴	Maffey-Ward et al ²⁵	Newcomer et al ²¹	O'Sullivan et al ¹⁵	O'Sullivan et al ¹²	Sheeran et al ¹⁶
Outcome data	15	0	1	1	1	1	1	1	1	1	0	0	1	0
Main results	16a	0	1	0	0	0	0	1	0	0	1	0	1	0
	16b	0	0	0	0	0	0	0	0	0	0	0	0	0
	16c	0	0	0	0	0	0	0	0	0	0	0	0	0
Discussion														
Other analysis	17	1	1	0	1	1	1	1	1	0	0	1	1	0
Key result	18	1	1	1	1	1	1	0	0	1	0	1	1	1
Limitation	19	1	1	0	0	1	0	0	0	0	0	1	1	0
Interpretation γ	20	1	1	1	1	1	1	1	1	0	1	1	1	1
Generalizability	21	1	1	1	1	1	1	1	1	1	1	1	1	1
Other information (funding)	22	1	1	0	1	0	1	1	1	0	0	1	0	1

STROBE indicates strengthening the reporting of observational studies in epidemiology.

larger AE than healthy controls. The overall heterogeneity of study effects was considerable ($I^2 = 83\%$, $P < 0.05$); it was no longer restricted to studies with poor quality of reporting but to all studies included in the meta-analysis. Heterogeneity did not change when single studies were excluded from the meta-analysis.

Two studies were included in a meta-analysis on VE (Figure 3). The overall EF for VE of 0.60 (95% CI, -0.23–1.43) illustrates that patients with NSCLBP have a higher deviation of the RE than healthy controls. The heterogeneity of study effects was substantial and significant ($I^2 = 84\%$, $P = 0.1$).

Three studies were included in a meta-analysis of CE (Figures 4, 5). Again, the studies were subgrouped, according to the age of participants, into adults^{15,16} and adolescents¹⁴ and further for FP and AEP. The overall EF for CE for FP, 0.39; (95% CI, -1.09 to 0.3) indicates that patients with FP NSCLBP undershoot into flexion compared with healthy controls. The overall EF for CE for AEP, 0.18; 95% CI, -0.3 to 0.65 indicates that patients with AEP NSCLBP overshoot into extension compared with healthy controls. However, the results are not significant. The adolescent sample in the study by Astfalck *et al*¹⁴ showed a reverse pattern. The heterogeneity of study effects for the FP subgroup was considerably ($I^2 = 75\%$, $P < 0.05$). Removing the study of Astfalck *et al*¹⁴ lowered the heterogeneity considerably ($I^2 = 26\%$, $P = 0.24$). The heterogeneity of study effects for the AEP subgroup was negligible ($I^2 = 36\%$, $P = 0.21$).

DISCUSSION

The results of this study indicate that lumbar reposition sense is impaired in patients with NSCLBP compared with healthy controls. In the majority of the studies, patients with NSCLBP produced a greater AE and VE than healthy controls. In addition, patients with FP NSCLBP tend to undershoot into flexion while patients with AEP NSCLBP overshoot into extension. Recent studies tend to report RE for FP and AEP subgroups of patients with NSCLBP based on a better and improved understanding of NSCLBP. These studies showed that the direction of RE differs between subgroups. AE and CE tend to show larger EFs than VE.

The meta-analysis is based on data of neutral-slumped-neutral sitting^{12,14–16} because these studies used a comparable measurement procedure and patient criteria. The meta-analysis showed similar findings for adults and adolescents regarding AE and VE.

However, study limitations render firm conclusions unsafe. The quality of reporting and the authors' appraisal of risk of bias, in some studies, were limited. Some studies recruited only small samples.^{12,15,18,20–25}

In some studies, the inclusion and exclusion criteria were imprecise, which however did not affect the studies of the meta-analysis.^{11,17,20}

It is hypothesized that reduced proprioception is present in the group of CLBP disorders where patients present movement or control impairments.³ Shortcomings in former studies to screen for this specific group and exclude patients with underlying red flag disorders, specific pathoanatomical

TABLE 5. Reliability and Measurement Error

Author	Reliability	Measurement Error	Conclusion
Koumantakis et al ¹⁹	NSCLBP: all RE tests ICC = 0.24–0.64 AE for flexion and rotation: ICC = 0.76–0.80 Other RE tests: ICC = 0.2–0.69	NSCLBP: SEM = 0.45°–1.34° (large) HC: SEM = 0.45°–3.90°	Low ICC and high SEM The reliability is low in patients with LBP
Asell et al ⁷	Only tested in HC and with a slightly modified of the sitting pelvic test VE: ICC = 0.75 CE: ICC = 0.86		Reliability is acceptable
Descarreaux et al ²⁰	Not specified	Not specified	
Astfalck et al ¹⁴	Maffey-Ward et al ⁵ and Lam et al ²⁴		This task has previously been shown to have good reliability in adults both with and without LBP ^{24, 25}
Newcomer et al ²¹		SEMean = 0.48°	
Newcomer et al ²²		SEMean = 0.27°	SEM decreased compared with the previous study
Lam et al ²⁴	No difference in error magnitude between days	No difference in error magnitude between days	Suggest that either the study group did not have kinesthetic deficits associated with their condition or that the repositioning test in the sitting position lacks sensitivity
Georgy ¹⁸	Not specified	Not specified	
O'Sullivan et al ¹²	Reliability is only indicated for the measurement device	Measurement error is only indicated for the measurement device	Reliability and measurement error are not specified for the testing protocol
O'Sullivan et al ¹⁵	ICC >0.80 for the measurement device ⁴²	Small measurement error for the measurement device ⁴²	This device has been shown to have very good reliability and measurement error for the measurement of lumbopelvic posture
Sheeran et al ¹⁶	Reliability is only indicated for the measurement device (spinal wheel ICC = 0.95–0.98) ⁴³		

NSCLBP indicates nonspecific chronic low back pain; RE, reposition error; AE, absolute error; CE, constant error; SEM, intraclass correlation coefficient; SEM, standard error of the measurement; SEMean, standard error of the mean; HC, healthy controls; ICC, intraclass correlation coefficient; SEM, standard error of the measurement; SEMean, standard error of the mean; LBP, low back pain.

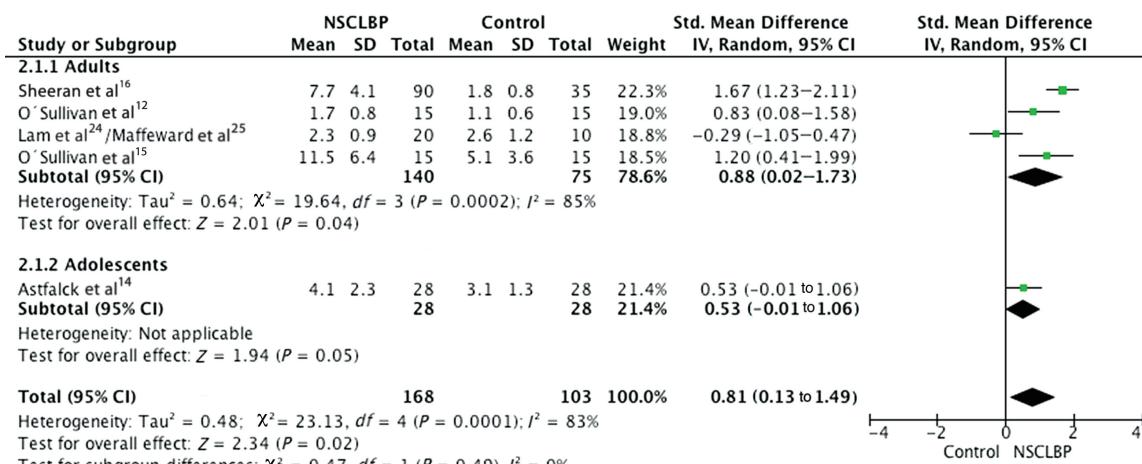


Figure 2. Forrest plot showing the results of the meta-analysis of AE subgrouped for adults and adolescents. The overall EF of 0.81, 95% CI, 0.13–1.49 picture that patients with unspecific LBP have a larger AE than healthy controls. AE indicates absolute error; CI, confidence interval; NSCLBP, nonspecific chronic low back pain; SD, standard deviation; EF, effect size; LBP, low back pain.

disorders, and pain disorders with a dominance of nonorganic factors may have added to the inconsistency of the findings.^{17,19,20} Only 5 studies reported attempts to minimize selection bias by using matching criteria.^{12,14,15,17,23}

However, within the meta-analysis, studies that included patients with NSCLBP with dominant physical factors were included.

The measurement approach varied considerably among studies. Different testing positions, number of repetitions, movement instructions, and measurement systems make it difficult to compare findings. Some studies used a warm-up phase, practice trials, or demonstrations,^{11,12,18} whereas others did not.^{16,21}

The most frequently used test position was sitting.^{11,12,15–17} The test positions can influence the results of lumbar position sense testing as proprioceptive input may differ depending on which segment of the spine moves (proximal or distal segment) and on the loading of the spine (unloaded *vs.* loaded). As lumbar RE seems direction specific in FP and AEP NSCLBP populations, the tested movement direction might influence the

outcome.^{14,16,26} Measurement systems varied and the scale and accuracy of these systems may differ and affect the measurement outcome when measuring small angular differences. The placement of devices/markers varied considerably with some studies assessing the total lumbar spine,^{12,16,17,21,24,25} whereas others assessed the lower part of the lumbar spine^{14,15,18} or larger areas.^{22,23} The number of repetitions varied between studies and ranged from 3 to 10.^{14,17} The number of repetitions influences the stability of the results.

Several studies reported only one specific aspect of RE, usually AE, which limited the information that could be extracted from these studies.^{18,19,21,23–25} The definitions of AE, CE, and VE were described rather vaguely in some studies.^{16,18,20,23} This hampers comparability because it is not clear if the same mathematical definition was used for the same type of error.

Recommendations for Future Research

Future studies, using sufficiently large, matched sample sizes should use adequate screening and diagnostic instruments including the O’Sullivan classification system,³⁵ imagining

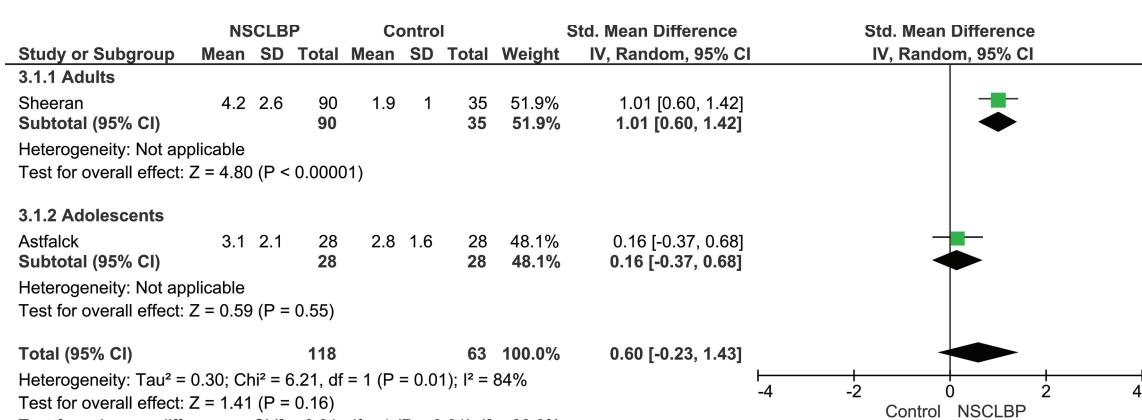


Figure 3. Forrest plot showing the results of the meta-analysis of VE subgrouped for adults and adolescents. The overall mean difference of 0.57, 95% CI, 0.05–1.09 illustrate that patients with unspecific LBP have a higher deviation of reposition error than healthy controls. VE indicates variable error; CI, confidence interval; NSCLBP, nonspecific chronic low back pain; SD, standard deviation; LBP, low back pain.

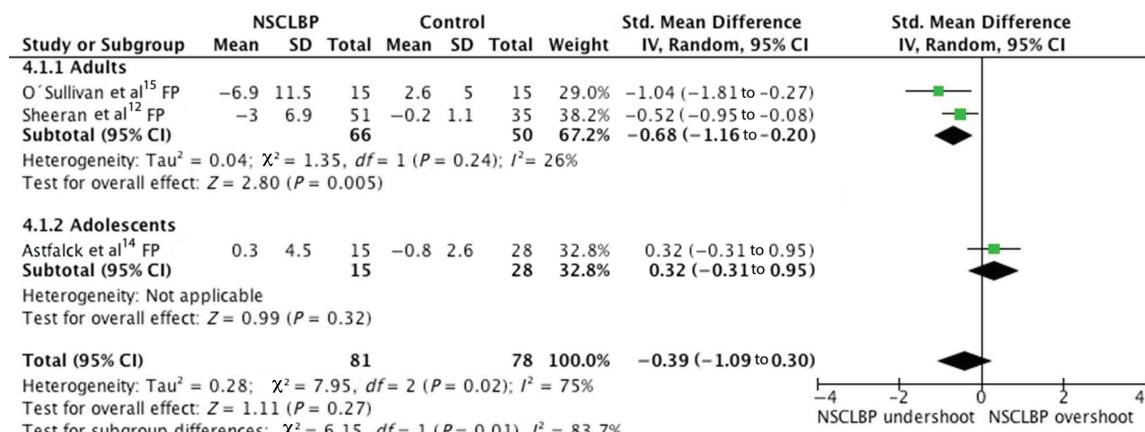


Figure 4. Forrest plots showing the results of a meta-analysis on CE subgrouped for adults and adolescents. The overall mean difference CE for FP is -0.39 (95% CI, -1.09 to 0.3) indicates that patients with FP NSCLBP undershoot into flexion. CE indicates constant error; CI, confidence interval; FP, flexion pattern; NSCLBP, nonspecific chronic low back pain; SD, standard deviation.

techniques, response to facet-joint injection, and questionnaires such as the STarT Back screening tool,³⁶ the Orebro questionnaire,³⁷ or the fear-avoidance beliefs questionnaire.³⁸ Collaboration between allied health and medical professions is required to elucidate the veracity of their hypotheses and for precise patient and control selection.

For future studies, we recommend a test position and movement directions that are reported as an aggravating factor by the tested population, such as flexion and extension in sitting for patients with CLBP with physical factors.^{12,15,16} We further recommend an analysis of criterion validity and between-day reliability of both measurement error and reliability of the measurement device and approach, a standardized and validated placement of the devices and defining the adequate number of repetitions through a D-study.^{39,40}

We recommend that authors present exact formulas for AE, CE, and VE and suggest the following definitions, with E being the expected error (E) that is equivalent to the mean error in finite populations:

AE is the mean absolute difference between the starting (Θ) and final position (X).

$$AE = E [|X - \Theta|]$$

CE is the mean signed difference between Θ and X .

$$CE = E [X - \Theta]$$

VE is the square root of the error variance.

$$VE = \sqrt{Var (|X - \Theta|)}$$

We recommend continuing to evaluate various aspects of error (AE, CE, and VE). Other aspects of RE are hardly mentioned in this review. Movement time or velocity,²⁰ learning phase, mean-squared RE, and the relevance of visual or verbal feedback need to be investigated. Further prospective randomized controlled trials (RCTs) are needed to assess if improvements in movement control are associated with improvements in proprioception. The association of lumbar RE errors to other movement dysfunctions and other dimensions of LBP

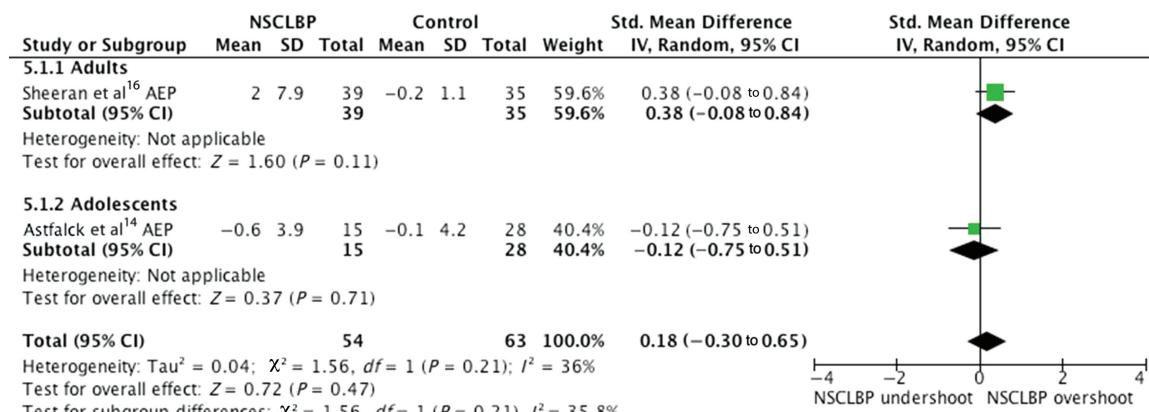


Figure 5. Forrest plots showing the results of a meta-analysis on CE subgrouped for adults and adolescents. The overall mean difference CE for AEP is 0.18 (95% CI, -0.3 to 0.65) indicates that patients with AEP NSCLBP overshoot into extension. CE indicates constant error; CI, confidence interval; AEP, active extension pattern; NSCLBP, nonspecific chronic low back pain; SD, standard deviation.

should be assessed. In summary, only a large, well-powered, prospective randomized controlled trial with a standardized measurement approach can address the hypothesis that proprioception is impaired in patients with CLBP with physical factors and treatable through a classification-guided intervention.

Limitations of This Study

It has been discussed that using a funnel plot should assess publication bias when 10 or more studies can be pooled. As only 6 studies were included in the meta-analysis, a funnel plot would have been inconclusive regarding publication bias.⁴¹ We considered a factor analysis of elements in the study design that would determine if a study found differences between patients with NSCLBP and controls. However, because of the limited number of studies and the great variety in study designs, this was not possible. Therefore, we focused to choose the presented qualitative appraisal of methodological differences and their effect on the study design.

Clinical Implication

Clinical measures of RE are being used to assess proprioceptive deficits. The studies included in this review and meta-analysis strengthens the assumption that patients with NSCLBP produce greater RE than healthy controls and, therefore, have proprioceptive deficits compared with healthy controls. So far, only 1 study has investigated the responsiveness of RE to treatment. This study has shown an improvement in pain and RE after a classification-guided intervention.^{3,26} Until conclusions can be drawn from larger studies, we propose clinical interpretation of RE with caution.

CONCLUSION

Although patients seemed to produce a larger lumbar RE compared with healthy controls, study limitations render firm conclusions unsafe. Future studies should pay closer attention to power, precision, and reliability of the measurement approach, definition of outcome measures and patient selection. We recommend a large, well-powered, prospective randomized control study that uses a standardized measurement approach and definitions for AE, CE, and VE to address the hypothesis that proprioception may be impaired with CLBP.

➤ Key Points

- Patients with NSCLBP tend to produce a larger lumbar RE compared with healthy controls.
- The applied test procedures and instrumentation varied between studies.
- We recommend a standardized measurement approach and the use of standardized and accurate definitions for lumbar RE to be used in future studies.

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