

Review

# Can We Identify Subgroups of Patients with Chronic Low Back Pain Based on Motor Variability? A Systematic Scoping Review

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Supplementary Materials S1– Search Strategy

Final search was conducted on September 16<sup>th</sup>, 2021.

## Sample of PubMed search strategy

#	Search Statement	Results
1	(Chronic*[tiab] OR recurr*[tiab] OR aspecific*[tiab])	171117
2	("low back pain"[MeSH Terms] OR low back pain*[tiab] OR low backache*[tiab] OR low back ache*[tiab] OR lower back pain*[tiab])	35736
3	(variability[tiab] OR variation*[tiab])	690017
4	("Movement"[Mesh] OR movement*[tiab] OR task[tiab] OR motor*[tiab])	1242536
5	#1 AND #2 AND #3 AND #4	107

## Sample of EMBASE search strategy

#	Search Statement	Results
1	(Chronic*:ti,ab OR recurr*:ti,ab OR aspecific*:ti,ab)	2435787
2	('low back pain'/exp OR "low back pain*":ti,ab OR "low backache*":ti,ab OR "low back ache*":ti,ab OR "lower back pain*":ti,ab)	63533
3	(variability:ti,ab OR variation*:ti,ab)	1108206
4	('movement (physiology)'/exp OR movement*:ti,ab OR task:ti,ab OR motor*:ti,ab)	1308513
5	#1 AND #2 AND #3 AND #4	131

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**Sample of Web of Science search strategy**

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#	Search Statement	Results
1	(Chronic* OR recurr* OR aspecific*)	1777551
	("low back pain" OR "low back pain*" OR "low backache*" OR "low back ache*" OR "lower back pain*")	
2		44346
	(variability OR variation*)	
3		2094393
4	(movement* OR task* OR motor*)	1518727
5	#1 AND #2 AND #3 AND #4	<b>163</b>

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## Supplementary Materials S2 – Quality Assessment

Modified Downs and Black checklist for the assessment of the methodological quality of both randomized and non-randomized studies.

Item	Criteria	Possible Answer
<b>Reporting</b>		
1	<i>Is the hypothesis/aim/objective of the study clearly described?</i>	Yes = 1 No = 0
2	<i>Are the main outcomes to be measured clearly described in the Introduction or Methods section?</i> If the main outcomes are first mentioned in the Results section, the question should be answered no.	Yes = 1 No = 0
3	<i>Are the characteristics of the patients included in the study clearly described?</i> In cohort studies and trials, inclusion and/or exclusion criteria should be given. In case-control studies, a case-definition and the source for controls should be given.	Yes = 1 No = 0
4	<i>Are the interventions of interest clearly described?</i> Treatments and placebo (where relevant) that are to be compared should be clearly described.	Yes = 1 No = 0
5	<i>Are the distributions of principal confounders in each group of subjects to be compared clearly described?</i> A list of principal confounders is provided.	Yes = 2 Partially = 1 No = 0
6	<i>Are the main findings of the study clearly described?</i> Simple outcome data (including denominators and numerators) should be reported for all major findings so that the reader can check the major analyses and conclusions. (This question does not cover statistical tests which are considered below).	Yes = 1 No = 0
7	<i>Does the study provide estimates of the random variability in the data for the main outcomes?</i> In non-normally distributed data the interquartile range of results should be reported. In normally distributed data the standard error, standard deviation or confidence intervals should be reported. If the distribution of the data is not described, it must be assumed that the estimates used were appropriate and the question should be answered yes.	Yes = 1 No = 0
10	<i>Have actual probability values been reported (e.g. 0.035 rather than &lt;0.05) for the main outcomes except where the probability value is less than 0.001?</i>	Yes = 1 No = 0
<b>External Validity</b>		
11	<i>Were the subjects asked to participate in the study representative of the entire population from which they were recruited?</i> The study must identify the source population for patients and describe how the patients were selected. Patients would be representative if they comprised the entire source population, an unselected sample of consecutive patients, or a random sample. Random sampling is only feasible where a list of all members of the relevant population exists. Where a study does not report the proportion of the source population from which the patients are derived, the question should be answered as unable to determine.	Yes = 1 No = 0 Unable to determine = 0
12	<i>Were those subjects who were prepared to participate representative of the entire population from which they were recruited?</i> The proportion of those asked who agreed should be stated. Validation that the sample was representative would include demonstrating that the distribution of the main confounding factors was the same in the study sample and the source population.	Yes = 1 No = 0 Unable to determine = 0
<b>Internal Validity</b>		
15	<i>Was an attempt made to blind those measuring the main outcomes of the intervention?</i>	Yes = 1 No = 0 Unable to determine = 0

16	<i>If any of the results of the study were based on “data dredging”, was this made clear? Any analyses that had not been planned at the outset of the study should be clearly indicated. If no retrospective unplanned subgroup analyses were reported, then answer yes.</i>	Yes = 1 No = 0 Unable to determine = 0
18	<i>Were the statistical tests used to assess the main outcomes appropriate? The statistical techniques used must be appropriate to the data. For example nonparametric methods should be used for small sample sizes. Where little statistical analysis has been undertaken but where there is no evidence of bias, the question should be answered yes. If the distribution of the data (normal or not) is not described it must be assumed that the estimates used were appropriate and the question should be answered yes.</i>	Yes = 1 No = 0 Unable to determine = 0
20	<i>Were the main outcome measures used accurate (valid and reliable)? For studies where the outcome measures are clearly described, the question should be answered yes. For studies which refer to other work or that demonstrates the outcome measures are accurate, the question should be answered as yes.</i>	Yes = 1 No = 0 Unable to determine = 0
<b>Confounding</b>		
21	<i>Were the patients in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited from the same population? For example, patients for all comparison groups should be selected from the same hospital. The question should be answered unable to determine for cohort and case-control studies where there is no information</i>	Yes = 1 No = 0 Unable to determine = 0
22	<i>Were study subjects in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited over the same period of time? For a study which does not specify the time period over which patients were recruited, the question should be answered as unable to determine.</i>	Yes = 1 No = 0 Unable to determine = 0
25	<i>Was there adequate adjustment for confounding in the analyses from which the main findings were drawn? This question should be answered no for trials if: the main conclusions of the study were based on analyses of treatment rather than intention to treat; the distribution of known confounders in the different treatment groups was not described; or the distribution of known confounders differed between the treatment groups but was not taken into account in the analyses. In non-randomized studies if the effect of the main confounders was not investigated or confounding was demonstrated but no adjustment was made in the final analyses the question should be answered as no.</i>	Yes = 1 No = 0 Unable to determine = 0
26	<i>Were losses of patients to follow-up taken into account? If the numbers of patients lost to follow-up are not reported, the question should be answered as unable to determine. If the proportion lost to follow-up was too small to affect the main findings, the question should be answered yes.</i>	Yes = 1 No = 0 Unable to determine = 0
<b>Power</b>		
27	<i>Did the study have sufficient power to detect a clinically important effect where the probability value for a difference being due to chance is less than 5%? Sample sizes have been calculated to detect a difference of x% and y%.</i>	Yes = 1 No = 0 Unable to determine = 0

Supplementary Materials S3 - Methodological Quality

**Modified Downs and Black Checklist**

<b>Internal validity</b>	<b>Confounding</b>	<b>Reporting Power</b>	<b>External</b>	<b>Validity</b>
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<i>Cross-sectional studies</i>	1	2	3	4	5	6	7	10	%	11	12	%	15	16	18	20	%	21	22	25	26	%	27	%	TOTAL		
(M. Asgari et al., 2015) [34]	1	1	1	1	NA	1	1	1	100,0	0	0	0	0	1	1	1	75	NA	NA	1	NA	100	0	0	73,3		
(N. Asgari et al., 2017) [48]	1	1	1	1	NA	1	1	1	100,0	0	0	0	0	1	1	1	75	NA	NA	1	NA	100	0	0	73,3		
(Azadinia et al., 2020) [51]	1	1	1	1	NA	1	1	1	100,0	1	0	50	0	1	1	1	75	NA	NA	1	NA	100	0	0	86,7		
(Bagheri et al., 2020) [41]	1	1	1	1	NA	1	1	1	100,0	1	0	50	0	1	1	1	75	NA	NA	0	NA	0	1	100	72,2		
(Chehrehrizi et al., 2017) [35]	1	1	1	1	NA	1	1	1	100,0	1	0	50	0	1	1	1	75	NA	NA	0	NA	0	1	100	80,0		
(Dideriksen et al., 2014) [49]	1	1	1	1	NA	1	1	1	100,0	1	0	50	0	1	1	1	75	NA	NA	1	NA	100	0	0	80,0		
(Ebrahimi et al., 2017) [42]	1	1	1	1	NA	1	1	1	100,0	0	0	0	0	1	1	1	75	NA	NA	0	NA	0	0	0	66,7		
(Falla et al., 2014) [50]	1	1	1	1	NA	1	1	0	85,7	1	0	50	0	1	1	1	75	NA	NA	1	NA	100	0	0	73,3		
(D. Hamacher, Hamacher, Herold, et al., 2016) [39]	1	1	0	1	NA	1	1	1	85,7	0	0	0	0	1	1	1	75	NA	NA	0	NA	0	1	100	66,7		
(D. Hamacher, Hamacher, Krowicki, et al., 2016) [40]	1	1	0	1	NA	1	1	1	85,7	1	0	50	0	1	1	1	75	NA	NA	0	NA	0	0	0	66,7		
(D. D. Hamacher et al., 2014) [43]	1	1	0	1	NA	1	1	1	85,7	1	0	50	0	1	1	1	75	NA	NA	0	NA	0	1	100	73,3		
(van den Hoorn et al., 2012) [46]	1	1	1	1	NA	1	1	1	100,0	0	0	0	0	1	1	1	75	NA	NA	1	NA	100	0	0	73,3		
(Jacobs et al., 2009) [28]	1	1	1	1	NA	1	1	1	100,0	0	0	0	0	1	1	1	75	NA	NA	1	NA	100	0	0	73,3		
(Lamoth, Meijer, et al., 2006) [45]	1	1	1	1	NA	1	1	1	100,0	1	0	50	0	1	1	1	75	NA	NA	1	NA	100	0	0	80,0		
(Lamoth, Daffertshofer, et al., 2006) [44]	1	1	1	1	NA	1	1	1	100,0	1	0	50	0	1	1	1	75	NA	NA	1	NA	100	0	0	80,0		
(Lamoth et al., 2008) [38]	1	1	1	1	NA	1	1	0	85,7	1	0	50	0	1	1	1	75	NA	NA	1	NA	100	1	100	84,4		
(Mazaheri et al., 2010) [52]	1	1	1	1	NA	1	1	1	100,0	1	0	50	0	1	1	1	75	NA	NA	1	NA	100	1	100	86,7		
(McCaskey et al., 2018b) [53]	1	1	1	1	NA	1	1	1	100,0	1	0	50	0	1	1	1	75	NA	NA	1	NA	100	0	0	80,0		
(Mehravari et al., 2012) [54]	1	1	1	1	NA	1	1	0	85,7	0	0	0	0	1	1	1	75	NA	NA	1	NA	100	0	0	66,7		
(Mokhtarinia et al., 2016) [36]	1	1	1	1	NA	1	1	1	100,0	0	0	0	0	1	1	1	75	NA	NA	1	NA	100	0	0	73,3		
(Tajali et al., 2013) [55]	1	1	1	1	NA	1	1	0	85,7	0	0	0	0	1	1	1	75	NA	NA	1	NA	100	0	0	66,7		
(Vogt et al., 2001) [47]	1	1	1	1	NA	1	1	0	85,7	0	0	0	0	1	1	1	75	NA	NA	0	NA	0	0	0	60,0		
<b><i>Longitudinal studies</i></b>																											
(Bagheri et al., 2019) [56]	1	1	1	1	1	1	1	1	100,0	0	0	0	0	1	1	1	75	1	0	1	NA	33,3	1	100	77,8		
(McCaskey et al., 2018a) [58]	1	1	1	1	1	1	1	1	100,0	1	0	50	1	1	1	1	100	1	0	1	1	75	0	0	84,2		
(Tsao & Hodges, 2008) [57]	1	1	0	1	NA	1	1	1	75,0	0	0	0	0	1	1	1	75	NA	NA	0	NA	0	0	0	60,0		

Supplementary Materials S4 – Characteristics of included studies

**Table S1** Motor variability during bending tasks in patients with CLBP and healthy controls.

Author (year)	CLBP N		Healthy controls N		Pain CLBP (months)	Baseline mean (SD)	Motor Performed bending task	Motor variable(s)*	(↑) - Higher (↓) - Lower (↔) – No significant difference CLBP and Controls
	Study design (QoE)	Age, Weight, Stature, BMI mean (SD)	Age, Weight, Stature, BMI mean (SD)						
(M. Asgari et al., 2015) [34]	CS (M)	N: 14 M Age: 31.5(6.6) yrs Weight: 74.8(8.8) kg Stature: 1.77(0.08) m BMI: 23.8(3.4) kg/m <sup>2</sup>	N: 12 M Age: 28.0(4.4) yrs Weight: 74.1(11.7) kg Stature: 1.73(0.08) m BMI: 24.5(3.5) kg/m <sup>2</sup>	>3 <sup>+</sup>	VAS: <2 <sup>+</sup>	30 trunk flexion-extension movements, 20 & 40 cycles/min, at self-selected speed	3D kinematics of the trunk	At self-selected speed, long-term (4-10 cycles) divergence exponents (maximum LyE) of trunk movements CLBP, M=0.001 (0.005) ↓ Controls, M = 0.015 (0.005), p=0.03	
(Chehrehrazi et al., 2017) [35]	CS (H)	N: 22 M Age: 23.9(3.3) yrs Stature: 1.77(0.07) m BMI: 30.2(6.1) kg/m <sup>2</sup>	N: 22 M Age: 27.4(5.1) yrs Stature: 1.74(0.08) m BMI: 23.5(3.5) kg/m <sup>2</sup>	>12 <sup>+</sup>	VAS: <2 <sup>+</sup>	30 (metronomically tuned) trunk flexion-extension movements, 3 conditions with 2 levels; symmetric and asymmetric, 20 and 40 cycles/minute, with (8kg) and without loading	3D kinematics of the trunk	Variability along the GEM (SD of time series, goal-equivalent) CLBP ↔ Controls, p=0.41  variability perpendicular to the GEM (SD of time series, non-goal equivalent) CLBP ↔ Controls, p=0.82  Relative proportion of variability along the GEM (goal-equivalent/non-goal equivalent) CLBP ↔ Controls, p=0.24	
(Mokhtarinia et al., 2016) [36]	CS (M)	N: 22 M Age: 30.2(6.1) yrs Weight: 74.5(7.7) kg Stature: 1.77(0.07) m BMI: 23.9(3.3) kg/m <sup>2</sup>	N: 22 M Age: 27.4(5.1) yrs Weight: 71.4(10) kg Stature: 1.74(0.08) m BMI: 23.5(3.5) kg/m <sup>2</sup>	>12 <sup>+</sup>	VAS: <2 <sup>+</sup>	30 (metronomically tuned) trunk flexion-extension movements 3 conditions with 2 levels; symmetric and asymmetric,	Lumbar, pelvis and thigh angular displacements (sagittal plane)	DP lumbar-pelvis coupling during high velocity (CLBP = 10.09 (3.97), controls = 13.13 (4.10), symmetric (CLBP = 10.79 (4.03), controls = 10.58 (4.16), asymmetric (CLBP = 7.94 (3.20), controls= 13.35 (4.27); During high velocity and asymmetry DP lumbar-pelvis coupling CLBP ↓ Controls, p<0.001	

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	20 and 40 cycles/minute , high and low velocity, with and without loading (8kg)	Three-way interaction effect Symmetry x Velocity x Group was significant (p=0.03)
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*Abbreviations:* QoE, Quality of Evidence; CS, cross sectional; BMI, Body Mass Index; VAS, Visual Analogue Scale, SD, standard deviation; LyE; Lyapunov Exponent, GEM, Goal Equivalent Manifold, DP; Deviation Phase, H, High Quality; M, Moderate Quality.

\*Only those variables that are used in the variability analysis are reported here.

†Inclusion criteria for the study (mean not reported).

**Table S2** Motor variability during gait in patients with CLBP and healthy controls.

Author (year)	Study design (QoE)	CLBP N (Male/Female), Age, Weight, Stature, BMI mean (SD)	Healthy controls N (Male/Female), Age, Weight, Stature, BMI mean (SD)	Pain Duration CLBP (months)	Baseline mean (SD)	Performed gait task	Motor variable(s)*	(↑) - Higher (↓) - Lower (↔) – No significant difference CLBP and Controls
(Bagheri et al., 2020) [41]	CS (M)	N: 15 (7/8) Age: 35.5(3.4) yrs Weight: 69.3(11.6) kg Stature: 1.68(0.97) m BMI: 24.6 <sup>v</sup> kg/m <sup>2</sup>	N: 12(4/8) Age: 4.1(3.4) yrs Weight: 72.5(7.8) kg Stature: 1.69(9.2) m BMI: 25.4 <sup>v</sup> kg/m <sup>2</sup>	>3 <sup>+</sup>	ODI: 12.4 (5.9) NRPS: 5.55 (1.7)	Overground 9 x 10-m, self-selected speed	3D kinematics trunk-pelvis	Pattern variability trunk-pelvis coupling CLBP ↓ Controls sagittal (CLBP = 16.69 (8.51), control = 33.56 (16.09), p=0.01) frontal (CLBP = 37.21 (15.6), control = 55.56 (21.19),p=0.05) transverse (CLBP = 25.13 (23.2), control = 48.9 (16.2), p=0.03) offset variability trunk – pelvis coupling CLBP ↔ Controls
(Ebrahimi et al., 2017) [42]	CS (M)	N: 10 (5/5) Age: 29.4 (6.38) yrs Weight: 68.07 (12.92) kg Stature: 1.64 (0.08)m BMI: 25.3 <sup>v</sup> kg/m <sup>2</sup>	N: 10 (5/5) Age: 29.6 (5.64)yrs Weight:62.38 (13.12)kg Stature: 1.67(0.07) m BMI: 22.4 <sup>v</sup> kg/m <sup>2</sup>	>3 <sup>+</sup>	ODI: 37.3 (12.7) NRPS: 5.1 (0.9)	Overground 20 x 8-m self-selected speed	kinematics of trunk-pelvis and lower extremities in the sagittal plane	Trunk-pelvis sagittal plane DP variability CLBP ↓ controls during stance (p=0.049, d=2.234) and swing (p=0.008,d=3.142) phase Pelvis-thigh DP over stance and swing phase CLBP ↓ controls (p<0.05)
(D. D. Hamacher et al., 2014) [43]	CS (M)	N: 12 Age: 51 (10) yrs	N: 12 Age: 51 (11) yrs	>3 <sup>+</sup>		Overground 25-m self-selected speed	3D angular trunk movements	Trunk CV during dual-task CLBP = 0.17 (0.07) deg/s ↑ controls = 0.12 (0.035) deg/s, p=0.044, η <sup>2</sup> =0.172
(D. Hamacher, Hamacher, Herold, et al., 2016) [39]	CS (M)	N: 12 Age: 55 (12) yrs	N: 12 Age: 57 (14) yrs	>3 <sup>+</sup>	VAS: >4 <sup>+</sup>	Overground 25 m with & without cognitive DT self-selected speed	Spatiotemporal parameter s; stride time, stride length, minimum toe clearance	CV stride time CLBP = 0.0203 (0.0128) ↑ controls = 0.0170 (0.0054) during single task, p=0.05 CV stride time CLBP = 0.0360 (0.0505) ↑ controls= 0.0199 (0.0231) during dual-task, p=0.01 CV minimum toe clearance or stride length variability CLBP ↔ Control during single and dual-task walking
(D. Hamacher, Hamacher, Krowicki, et	CS (M)	N: 14 Age: 57 (15) yrs	N: 14 Age: 59 (16) yrs	>3 <sup>+</sup>	VAS: >4 <sup>+</sup>	Overground 25 m with & without visual feedback	Spatiotemporal parameter s; stride time, stride length, minimum	CV minimum foot clearance diminished visual feedback trials CLBP = 28 (10) ↑ controls = 14 (5),p=0.001, η <sup>2</sup> =0.377 CV stride time diminished visual feedback trial CLBP = 3.5 (1.5) ↑

al., 2016) [40]					self-selected speed	foot clearance	controls = 2.3 (0.8), p=0.035, η <sup>2</sup> =0.159
(Lamoth, Meijer, et al., 2006) [45]	CS (H)	N: 19 (8/11) Age: 38 (21-52) yrs Weight: 74.4 (49-97) kg Stature: 1.7 (1.54-1.88) m BMI: 24.9 <sup>Y</sup> kg/m <sup>2</sup>	N: 14 (9/5) Age: 31 (20-46) yrs Weight: 72.5 (52-105) kg Stature: 1.80(1.58-1.98)m BMI: 22.4 <sup>Y</sup> kg/m <sup>2</sup>	1.2 yrs (3.5 months - 3 yrs)	TSK: 39 (6.8) RDQ: 10 (6) VAS: 5.6 (3.0)	Treadmill, 1, 1.4 km/h up to 7.0 km/h with increments of 0.8 km/h + trial with self-selected speed	3D kinematics angular movements of thoracic, lumbar, pelvic segments. EMG from bilateral ES Transverse; SD RP lumbar-pelvic CLBP ↓ controls, p=0.04 Frontal; SD RP CLBP ↑ controls thorax-pelvic, p<0.05; lumbar-pelvis, p<0.01 global pattern variability ES CLBP ↓ controls, p<0.01 Residual variability left/right ES CLBP ↑ controls, p<0.01

Table S2 (continued)

Author designation (year)	Study (QoE)	CLBP N (Male/Female), Age, Weight, Stature, BMI mean (SD)	Healthy controls N (Male/Female), Age, Weight, Stature, BMI mean (SD)	Pain Duration on CLBP (months)	Baseline mean (SD)	Performed gait task	Motor variable(s)*	(↑) - Higher (↓) - Lower (↔) - No significant difference CLBP and Controls
(Lamoth, Daffertshofer, et al., 2006) [44]	CS (H)	N: 12 (7/5) Age: 36.8 (10.9) yrs Weight: 72.4 (14.5) kg Stature: 1.74 (0.11) m BMI: 23.9 <sup>Y</sup> kg/m <sup>2</sup>	N: 12 (5/7) Age: 30 (8.1) yrs Weight: 73.3 (16.6) kg Stature: 1.80 (0.12)m BMI: 22.6 <sup>Y</sup> kg/m <sup>2</sup>	>3 <sup>+</sup>	-	Treadmill, at 6 velocities in fixed order; 6.2, 1.4, 3.8, 5.4, 2.2, 4.6 km/h	Angular trunk rotations relative to pelvis, EMG of bilateral ES	Residual variability thoracic-pelvic, lumbar-pelvic rotations transverse plane CLBP ↓ controls, p<0.01 Residual variability thorax, lumbar, pelvis rotations frontal plane CLBP ↑ controls variability, p<0.01 Left and right lumbar ES variability global (CLBP ↓ controls) and residual (CLBP ↑ controls), p<0.01
(Lamoth et al., 2008) [38]	CS (H)	N: 12 (6/6) Age: 45(9.2) yrs Weight: 76(10) kg Stature: 1.74(0.13) m BMI: 25.1 <sup>Y</sup> kg/m <sup>2</sup>	N: 14 (7/7) Age: 44(7.4) yrs Weight: 69(7) kg Stature: 1.76(0.06) m BMI: 22.3 <sup>Y</sup> kg/m <sup>2</sup>	7-15 yrs	VAS: 2.5-4.8	Treadmill, at 110 % of preferred speed, 4 conditions of attentional demands	3D kinematics (malleolus, thorax, pelvis)	Variability stride length CLBP (SD=3.6 cm) ↓ controls (SD=6.9 cm), p<0.01, f= 0.67 Variability step frequency / width CLBP ↔ controls Variability pelvis-thorax CLBP ↓ controls during task with high attentional demands (STROOP-INCO), p<0.05, d=1.09

(van den Hoorn et al., 2012) [46]	CS (M)	N: 13 (5/8) Age: 35.3(12.4) yrs Weight: 72.3(13.4) kg Stature: 1.75(0.13) m BMI: 23.6 <sup>y</sup> kg/m <sup>2</sup>	N: 12 (4/8) Age: 32.2(13.1) yrs Weight: 75.3(11.2) kg Stature: 1.72(0.10) m BMI: 25.5 <sup>y</sup> kg/m <sup>2</sup>	5 years (3-420 months)	VAS: 2.9 (1.5)	Treadmill, 12 speeds, from 0.5 to 1.72 m/s, increments of 0.11 m/s	Kinematics, joint rotations of pelvis, and trunk in transvers e plane	Trunk stride-to-stride variability transverse plane CLBP ↓ controls, p=0.002 Pelvis and thorax stride-to-stride variability separately CLBP ↔ controls
(Vogt et al., 2001) [47]	CS (M)	N: 34 (21/13) M: Age: 36.3(1.7) yrs Weight: 77.8(16.3) kg Stature: 1.73(0.09) m BMI: 25.8(4.1) kg/m <sup>2</sup> F: Age: 32.1(3.4) yrs Weight: 76.9(12.5) kg Stature: 1.76(0.06) m BMI: 24.8(3.3) kg/m <sup>2</sup>	N: 22 (16/6) M: Age: 34.8(5.2) yrs Weight: 77.6(6.5) kg Stature: 1.79(0.05)m BMI: 25.5(2.4) kg/m <sup>2</sup> F: Age: 29.4(1.3) yrs Weight: 71.5(4.9) kg Stature: 1.70(0.10) m BMI: 23.7(2.6) kg/m <sup>2</sup>	>12 <sup>†</sup>	VAS: 37 (30-53) ODI: 27.7 (24-48)	Treadmill, 4.5 km/h	3D kinematics (lumbar spinal movements)	CV pelvis rotations CLBP ↑ controls frontal (CLBP = 31.97 (8.41), control = 9.19 (3.04), p<0.001) sagittal (CLBP = 20.51 (7.29), control = 9.32 (1.92), p<0.001) transverse (CLBP = 23.70 (7.39), control = 12.07 (2.01), p<0.001) CV of the upper lumbar spine rotations CLBP ↑ controls frontal (CLBP = 14.97 (4.12), control = 9.41 (1.46), p< 0.001) sagittal (CLBP = 26.93 (5.71), control = 9.69 (1.03), p<0.001) transverse (CLBP = 26.45 (6.63), control = 12.34 (1.54), p<0.001)

Abbreviations: QoS, Quality of Evidence; CS, cross sectional, SD, Standard Deviation; ES, m. erector spinae; VAS, Visual Analogue Scale; *f*, Cohen’s *f*; *d*, Cohen’s *d*; ODI, Oswestry Disability Index; CV, Coefficient of Variation; H, High Quality; M, Moderate Quality, BMI<sup>y</sup>, BMI was not reported in the study but calculated manually; NRPS, Numerical Rating Pain Scale; BF, barefoot; DT, Dual Task; DP, deviation phase; η<sup>2</sup>, eta squared; TSK, Tampa Scale for Kinesiophobia; RDQ, Roland Disability Questionnaire; RP – Relative Phase.

<sup>y</sup>Only those variables that are used in the variability analysis are reported here.

<sup>†</sup>Inclusion criteria for the study (mean not reported).

**Table S3** Motor variability during lifting tasks in patients with CLBP and healthy controls.

Study (year)	Design (QoE)	CLBP N (Male/Female), Age, Weight, Stature, BMI mean (SD)	Healthy controls N (Male/Female), Age, Weight, Stature, BMI mean (SD)	Pain Duration in CLBP group (months)	Baseline Performed mean lifting task (SD)	Motor variables*)	(↑) - Higher (↓) - Lower (↔) – No significant difference CLBP and Controls
(N. Asgari)	CS (M)	N: 14 M Age: 25.33(3.45) yrs	N: 14 M Age: 23.15(2.04) yrs	>3 <sup>†</sup>	-	Repetitive lifting 2 equally	3D kinematics In progressive fatigue, maximum LyE hip CLBP ↓ Controls in

et al., 2017) [48]	BMI: 24.15(3.02) kg/m <sup>2</sup>	BMI: 22.42(2.44) kg/m <sup>2</sup>		sized dumbbells 15 % of BW, until fatigue (Borg Scale: 17)	(spine, hip, knee and ankle)	frontal (p=0.04) and transverse (p<0.01) plane In both early- and late fatigue, maximum LyE knee, ankle, spine angular movements CLBP ↔ Controls (p>0.05)
(Dideriksen et al., 2014) [49]	N: 17 (41%/59%) Age: 32.5(9.6) yrs Weight: 74.3(12.8) kg Stature: 1.77(0.10) m BMI: 23.6 <sup>y</sup> kg/m <sup>2</sup>	N: 17 (47%/53%) Age: 29.7(7.3) yrs Weight: 69.2(14.0) kg Stature: 1.75(0.10) m BMI: 22.6 <sup>y</sup> kg/m <sup>2</sup>	34.2 (29.3)	NRPS: 3.1(2.2) ODI: 14.2(7.2) TSK: 31.8(5.9) PCS: 16.1(8.5) STAI: 40.2(7.1)	Repetitive lifting (metronomically tuned), 5kg, 22 cycles	Angular movements in sagittal plane, 12 sensors evenly spaced (25 mm) along the spine %DET task related angular CLBP (99.83%) ↔ Controls (99.87%) %DET accessory angular trajectories in 8 of 12 segments CLBP ↑ compared to controls, p<0.05
(Falla et al., 2014) [50]	N: 19 (42%/58%) Age: 32.2(9.5) yrs Weight: 73.8(12.5) kg Stature: 1.77(0.09) m BMI: 23.6 <sup>y</sup> kg/m <sup>2</sup>	N: 17 (53%/47%) Age: 29.4(7.4) yrs Weight: 70.2(13.8) kg Stature: 1.76(0.1) m BMI: 22.7 <sup>y</sup> kg/m <sup>2</sup>	31.6 (28.2)	VAS: 3.1(2.0) ODI: 13.8(7.0) TSK: 32.1(6.8) PCS: 14.5(8.7) STAI: 40.1(7.2)	Repetitive lifting (metronomically tuned), 5kg, 25 cycles	MF distribution of muscle activity of LES end of the task CLBP ↓ controls, p<0.05 CLBP performed the task with the same region of the muscle activated (RMS EMG) over time, but EMG amplitude ↑

Abbreviations: QoE, Quality of Evidence; CS, cross sectional; BMI<sup>y</sup>, Body Mass Index was not reported but calculated manually; BW, body weight; LyE, Lyapunov Exponent; NRPS, Numerical Rating Pain Scale; ODI, Oswestry Disability Index; TSK, Tampa scale for Kinesiophobia; PCS, Pain Catastrophizing Scale; STAI, State Trait Anxiety Inventory; %DET, percentage of determinism; VAS, Visual Analogue Scale; ES, m. erector spinae; MF, mean power spectral frequency; RMS, root mean square; H, High Quality; M, Moderate Quality.

<sup>y</sup>Only those variables that are used in the variability analysis are reported here.

<sup>†</sup>Inclusion criteria for the study (mean not reported).

**Table S4** Motor variability during standing / sitting / and STS tasks in patients with CLBP and healthy controls.

Author (year)	Study design (QoE)	CLBP N (Male/Female), Age, Weight, Stature, BMI mean (SD)	Healthy controls N (Male/Female), Age, Weight, Stature, BMI mean (SD)	Pain Duration on CLBP (months)	Baseline mean (SD)	Performed standing / sitting / STS task	Motor variable(s)*	(↑) - Higher (↓) - Lower (⇔) – No significant difference CLBP and Controls
(Azadinia et al., 2020) [51]	CS (H)	N: 14(2/12) Age: 26.7(4.5) yrs Weight: 60.85(8.15) kg Stature: 1.66(0.06) m BMI: 22.1 <sup>y</sup> kg/m <sup>2</sup>	N: 12 (2/10) Age: 27.8(3.4) yrs Weight: 58.83(6.29) kg Stature: 1.62(0.03) m BMI: 22.4 <sup>y</sup> kg/m <sup>2</sup>	3.97 (2.41) yrs	VAS: 3.15(1.67) ODI: 21.01(7.47) TSK: 36.57(8.65)	Postural control 3 levels of difficulty; (i) RO (ii) RC (iii) FO	CoP parameter s (AP – ML directions)	Sample entropy CoP AP CLBP ↓ Controls Correlation dimension AP COP CLBP ↑ Controls
(Jacobs et al., 2009) [28]	CS (M)	N: 10 (5/5) Age: 39 (CI: 6) yrs BMI: 25 (CI: 1) kg/m <sup>2</sup>	N: 10 (5/5) Age: 35 (CI: 5) yrs BMI: 23 (CI: 3) kg/m <sup>2</sup>	>12 <sup>+</sup>	NRPS: 1.78(0.9) ODI: 13±7	Sitting, back unsupported, 75 trials of rapid arm raises	EMG from bilateral IO and ES, relative to deltoid onset	Variability (timing SD) APA onset latencies IO muscles CLBP ↓ Controls; contralateral IO (p=0.009) ipsilateral IO (p=0.045)
(Mazaheri et al., 2010) [52]	CS (H)	N: 22 (13/9) Age: 26.1(6.2) yrs Weight: 67.1(11.2) kg Stature: 1.72(0.1) m BMI: 22.7 <sup>y</sup> kg/m <sup>2</sup>	N: 22 (13/9) Age: 25.0(5.5) yrs Weight: 66.5(12.1) kg Stature: 1.73(0.1) m BMI: 22.2 <sup>y</sup> kg/m <sup>2</sup>	5.6 (4.1) yrs	RMDQ: 3.4(3.2)	Postural control 3 levels of cognitive demands; 3 levels of difficulty; (i) RO (ii) RC (iii) FO	CoP parameter s (AP – ML directions)	RQA revealed variability AP CoP sway CLBP ↓ Controls in terms of higher % recurrence and % determinism, lower trend by increasing level of cognitive difficulty
(Mehra var et al., 2012) [54]	CS (M)	N: 11 F Age: 23.2(2.9) yrs Weight: 52.4(4.1) kg Stature: 1.61(0.03) m BMI: 20.2 <sup>y</sup> kg/m <sup>2</sup>	N: 12 Age: 23.5(3.6) yrs Weight: 56(5.1) kg Stature: 1.60(0.04) m BMI: 21.9 <sup>y</sup> kg/m <sup>2</sup>	3.9 (1.9)	VAS: 1.1(1.1) ODI: 14.7(4.4)	STS, 3 difficulty levels; (i) RO (ii) RC (iii) NC	Full body kinematics CoM and head position	Joint configuration variability CLBP ↑ controls in trunk and head, p<0.05 PCs accounting for more than 90% of variance in unstable phase of the movement in RO and RC, CLBP (PCs = 2) ↓ Controls (PCs = 3)
(McCasky et al., 2018b) [53]	CS (H)	N: 24 (13/11) Age: 53.2 (24-75) yrs Weight: 71.4(11.2) kg Stature: 1.71(0.10) m	N: 34 (25/9) Age: 39.5 (22-67) yrs Weight: 68.3(11.0) kg Stature: 1.71(0.09)m	>3 <sup>+</sup>	VAS: 2.9(2.2) ODI: 20.1(10.1)	Postural control, sway perturbations predominantly in AP direction	Multi-joint kinematics (frontal/sagittal) and CoP/CoM	ApEn CoP AP during active response phase CLBP = 0.23 ⇔ Controls = 0.24, r=0.15

BMI: 24.4 <sup>y</sup> kg/m <sup>2</sup>	BMI: 23.4 <sup>y</sup> kg/m <sup>2</sup>	displacem ents
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**TABLE S4** (continued)

(Tajali et al., 2013) [55]	CS (M)	N: 11 F	N: 12	3.9 (1.9)	VAS: 1.1(1.1) ODI: 14.7(4.4)	STS, 3 difficulty levels; (i) RO (ii) RC (iii) NC	Full body kinematic s CoM and head position	Variability horizontal head position CLBP ↑ controls, p<0.05
		Age: 23.2 (2.9) yrs	Age: 23.5 (3.6) yrs					Vucm CLBP ↓ Controls for CoM (horizontal/vertical) and vertical head positions, p<0.05
		Weight: 52.4 (4.1) kg	Weight: 56 (5.1) kg					Vort horizontal head position CLBP ↑ Controls, p<0.05
		Stature: 1.61 (0.03) m	Stature: 1.60 (0.04) m					
		BMI: 20.2 <sup>y</sup> kg/m <sup>2</sup>	BMI: 21.9 <sup>y</sup> kg/m <sup>2</sup>					

*Abbreviations:* QoE, Quality of Evidence; CS, cross sectional; BMI<sup>y</sup>, Body Mass Index was not reported but calculated manually; VAS, Visual Analogue Scale; ODI, Oswestry Disability Index; TSK, Tampa scale for Kinesiophobia; RO, rigid surface eyes open; RC, rigid surface eyes closed; NC, narrow surface eyes closed; FO, foam surface eyes open; NRPS, Numerical Pain Rating Scale; IO, m. obliquus internus; ES, m. erector spinae; PCs, principal components; APA, Anticipatory Postural Adjustment; RMDQ, Roland Morris Disability Questionnaire; CoP, Center of Pressure; AP, anterior posterior; ML, mediolateral; RQA, Recurrence Quantification Analysis; CoM, Center of Mass; ApEn, approximate entropy; UCM, uncontrolled manifold approach; Vucm, variability per DOF with linearized UCM; Vort, variability per DOF perpendicular to linearized UCM; r, Pearson’s correlation; H, High Quality; M – Moderate Quality.

<sup>y</sup>Only those variables that are used in the variability analysis are reported here.

<sup>†</sup>Inclusion criteria for the study (mean not reported).

**Table S5** Longitudinal interventions: Motor variability over time in patients with CLBP

Author (year)	Study design (QoS)	Intervention group, N (Male/Female) Age, Weight, Stature, BMI mean (SD)	Control group, N (Male/Female) Age, Weight, Stature, BMI mean (SD)	Pain duration CLBP (months)	Baseline mean (SD)	Intervention and performed functional task	Motor variable(s)*	(↑) - Higher (↓) - Lower (⇔) - No significant difference CLBP and controls
(Bagheri et al., 2019) [56]	Control led clinical trial (H)	N: 15 CLBP (7/8) Age: 35.5 (3.39) yrs Weight: 69.3(11.6) kg Stature: 1.68(0.09) m BMI: 24.6 <sup>y</sup> kg/m <sup>2</sup>	N: 15 healthy (7/8) Age: 34.1(3.4) yrs Weight: 72.5(7.8) kg Stature: 1.69(0.09)m BMI: 25.4 <sup>y</sup> kg/m <sup>2</sup>	>3 <sup>+</sup>	VAS: 5.55(0.17) ODI: 12.4(5.9)	CSE, gait, self-selected speed, BF, pre- and post (6-weeks) intervention	3D trunk-pelvis kinematics	Pre-intervention: CVp trunk CLBP ↓ controls frontal (CLBP=37.21 (15.65),control=55.56 (21.19), p=0.01), transverse (CLBP=25.13 (25.88), control = 48.9 (26.22), p=0.03), sagittal (CLBP=16.69 (8.51), control=33.56 (16.09), p=0.01) Post intervention: CVp trunk frontal/transverse CLBP ⇔ Controls frontal (CLBP=56.09 (20.46), control=55.56 (21.19), p=0.9) & transverse (CLBP=41.04 (7.74), control=48.9 (26.22), p=0.3) CVp trunk sagittal CLBP ↓ controls (CLBP=22.39 (11.56), control=33.56 (16.09), p = 0.04) CLBP pre-post: NMPS (pre = 5.55 (1.74), post = 2.00 (1.32), p<0.001) ODI (pre = 12.44 (5.91), post = 5.00 (3.27), p<0.001)
(Tsao & Hodges, 2008) [57]	Longitudinal (M)	N: 9 CLBP (2/7) Age: 26 (7) yrs	-	2.8 (2) yrs	VAS = 4 PSFS = 6	MCT, gait, self-selected speed, assessments; baseline, 2-wks, 4-wks, 6-months	EMG of trunk muscles; TrA, OI, OE, RA, ES	CV EMG TrA ↓ after training and retained at 6-months follow-up, p<0.0015 CLBP pre-post (6-months): VAS: pre = 4 , post = 2, p = 0.0047 PSFS: pre = 6, post = 8.2, p<0.02 Relation VAS and CV TrA (r = -0.17, p > 0.67) Relation PSFS and CV TrA (r = -0.071, p > 0.86)
(McCauley et al., 2018a) [58]	Randomized Control Trial (H)	N: 11 CLBP (5/6) Age: 55 (32-75) yrs Weight: 71.8 (10.5) kg Stature: 1.72 (0.11) m BMI: 24.3 <sup>y</sup> kg/m <sup>2</sup>	N: 11 CLBP (5/6) Age: 54 (33-67) yrs Weight: 72.2(12.7)kg Stature: 1.7 (0.08)m BMI: 24.3 <sup>y</sup> kg/m <sup>2</sup>	>3 <sup>+</sup>	VAS: 2.5(0.7) ODI: 19.8(5.3)	Intervention Group 9 sessions PT combined with SMT (experimental) or SLT (control)	3D full body kinematics and CoP displacement	CoP ApEn and joint angle variability (UCM-index) in both CLBP groups ⇔ over time, d = 0.31 SMT improved ODI with 12 pp (CI = 5.3 pp to 17.7 pp, p< 0.001), but not significantly in the SLT 4 pp improvement (CI = 11.8pp to 19.2pp, d=0.20)

24.3 <sup>y</sup> kg/m <sup>2</sup>	<b>Group</b> VAS: 2.6(2.3) ODI: 17.6(10. 5)	task: standing	CLBP experimental group pre-post (4- wks): ODI: (pre = 20 , post = 8) VAS: (pre = 2.5, post = 1.55)
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*Abbreviations:* QoE, Quality of Evidence; BMI<sup>y</sup>, BMI was not reported in the study but calculated manually; NRPS, Numerical rating scale for pain; ODI, Oswestry Disability Index; CSE, core stabilization exercises; BF, barefoot; CVp, pattern variability; VAS, Visual Analogue Scale; PSFS, patient specific functional scale; MCT, motor control training; TrA, m. transversus abdominus; OI, m. obliquus internus abdominus; OE, m. obliquus externus abdominus; RA, m. rectus abdominus; ES, m. erector spinae; CV, coefficient of variation; r, Pearson's correlation; SMT, sensorimotor training; PT, physiotherapy; SLT, low-intensity exercises; CoP, Centre of Pressure; ApEn, Approximate Entropy; UCM, uncontrolled manifold approach; *d*, Cohen's *d*; pp, percentage points; CI, 95% confidence interval; H – High Quality; M, Moderate Quality.

<sup>y</sup>Only those variables that are used in the variability analysis are reported here.

<sup>†</sup>Inclusion criteria for the study (mean not reported).