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The effect and mechanism of motor control exercise on low back pain: a narrative review

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- Low back pain (LBP) is a common symptom that can occur in all ages. It is the first common cause of disability globally and is associated with over 60 million disability-adjusted life-years in a single year.
- Motor control exercise (MCE) has obtained increasing attention in treating LBP. However, the findings from distinct meta-analyses differed and some even reached controversial conclusions. More importantly, how MCE improves LBP-related symptoms remains unclear.
- The primary aim of this study is to describe the possible improvement mechanisms of MCE on LBP from brain, biochemistry, inflammatory, and neuromuscular aspects. The secondary aim is to further conclude its effectiveness and clinical application. Further understanding of mechanisms and effectiveness could be instructive for future LBP treatments and provide more information for clinicians when making prescriptions.
- MCE is effective in alleviating pain and disability among patients with acute and chronic LBP. Notably, the evidence for acute LBP is relatively low-quality and limited.
- MCE might be more effective for patients with specific LBP characteristics, especially those with pre-diagnosis of impaired transversus abdominis recruitment, intermediate pain intensity, and longer MCE training duration.
- MCE could remap brain representation and reverse negative brain alternation, induce exercise-induced hypoalgesia, mediate anti-inflammatory response, retain normal activation, and improve morphological deficits.

Keywords

- low back pain
- motor control exercise
- mechanism
- effect

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Introduction

Low back pain (LBP) is a highly prevalent disease affecting people of all ages. LBP is the first common cause of disability globally, and it is associated with over 60 million disability-adjusted life-years in 2015 (1). It is defined as pain located between the lower rib margins and the buttock creases with or without leg pain or other neuropathic symptoms in the lower extremities (2). Considering that the specific pathology causing LBP in approximately all patients cannot be accurately diagnosed, the percentage of non-specific LBP is large (about 90%). Nearly everyone will experience an acute LBP during their lifetime. Moreover, acute LBP will normally disappear within 1 year, and some will be persistent with low-to-moderate intensity and transform into chronic LBP (CLBP). Persistent LBP may not be a simple symptom but a disease with a biopsychosocial injury model (3) because patients with CLBP generally suffer from impaired physical and mental function, low quality of life, and work incapacity (4). Thus, LBP is a large societal and economic burden, which results in direct medical costs and relatively higher indirect costs. Especially, CLBP makes up 20% of all LBP, but its costs account for 80% of the direct costs (5).

Physical therapies are recommended for patients with LBP according to several guidelines (6, 7, 8, 9). Motor control exercise (MCE) has been obtaining increasing attention in recent years (5). MCE is defined as an exercise to increase control and coordination of the spine and pelvis (10). Normally, MCE increases the weak deep trunk muscles, such as transversus abdominis and multifidus, and reduces the overactive large external trunk muscles, such as rectus abdominal and erector spinae muscles (11). Multiple systematic reviews and meta-analyses have explored the positive effectiveness of MCE on LBP patients, such as improvement in pain and disability. However, the findings from distinct meta-analyses differed due to various inclusion criteria, such as the

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differences in participants, interventions, comparisons, and outcomes. Meanwhile, some studies reached several controversial results, which remained to be verified (11, 12, 13). Furthermore, as LBP is a complicated disease with many potential contributors, the underlying mechanisms of how MCE improves these functions have rarely been reported.

The primary aim of this study is to describe the possible improvement mechanisms of MCE on LBP from brain, biochemistry, inflammatory, and neuromuscular aspects. The secondary aim is to further conclude its effectiveness and clinical application. Further understanding of mechanisms and effectiveness could be instructive for future LBP treatments and provide more information for clinicians when making prescriptions.

Clinical effectiveness

To better summarize the clinical effectiveness of MCE on LBP, we searched the systematic reviews and meta-analyses exploring the effect of MCE on pain and disability among patients with LBP in the past 10 years. Detailed information including population, sample size, and searching period is provided in Table 1, and the comparisons and outcomes such as standard mean difference or mean difference were concluded in Table 2. Meanwhile, the quality of evidence was assessed using Assessment of Multiple Systematic Reviews (AMSTAR), ranging from 0 to 11. The quality was determined as low, moderate, and high when the AMSTAR score was less than 4, from 4 to 7, and over 7, respectively.

For patients with acute LBP, low-to-moderate quality of evidence indicated that MCE was as effective as spinal manipulative therapy or other types of exercise, and no additional benefit of MCE combined with medical management over medical management alone was found (11, 14). Meanwhile, the safety of MCE has been demonstrated by minor or no adverse events reported in clinical trials (10, 12). Notably, the additional MCE showed less than 64% risk of 1-year recurrence than medical management alone (risk ratio 0.36, 95% CI 0.18 to 0.72, $P = 0.004$). This finding indicated that applying MCE in the early phase of LBP could be a potential method to prevent the transition from acute to CLBP (15). The early application of MCE is feasible possibly because MCE includes cognitive awareness and isolated activation of deep trunk muscles during the initial stages of LBP, which less irritate pain (16). Nevertheless, the quality of evidence was limited due to inconsistency and small sample sizes.

In patients with CLBP, most results indicated that MCE provided patients with reduced pain intensity and improved physical function compared with no treatment or minimal intervention at short, intermediate, and long terms (5, 10, 13, 17). The MCE can effectively relieve pain by 26 points using visual analog scale and improve disability by 14% points using Oswestry Disability Index, which was clinically significant (5). Furthermore, low-to-high quality of evidence supported the superiority of MCE over control intervention in LBP and disability improvement (12, 13, 18, 19, 20, 21, 22). In particular, the short-term effect of MCE may be more stable and significant than that in the long term

Table 1 Quality, population description, population definition and search period of studies included in the systematic reviews and meta-analyses.

	Quality (AMSTAR)		Population			Population definition	
Source	Score	Quality	Pain type	Sample size, *n*	Studies, *n*	Pain duration	Search period
Owen *et al.* (5)	11/11	High	Chronic LBP	5578	89 RCTs	≥12 weeks	Inception to 05/2019
Bernard *et al.* (25)	9/11	High	Chronic LBP	200	6 RCTs	>12 weeks	Inception to 0/10/2018
Byström *et al.* (13)	6/11	Moderate	Chronic LBP	1768	16 RCTs	>12 weeks	Inception to 10/2011
Gomes-Neto *et al.* (24)	7/11	Moderate	Chronic LBP	895	11 RCTs	> 3 months + no leg pain	Inception to 11/2014
Luomajoki *et al.* (18)	11/11	High	LBP	781	11 RCTs	Chronic LBP: > 3 months; subacute LBP: within 3–12 weeks	Inception to 04/2017
Macedo *et al.* (14)	11/11	High	Acute LBP	197	3 RCTs	<6 weeks	Inception to 04/2015
Niederer *et al.* (23)	6/11	Moderate	Chronic LBP	2391	18 RCTs	NA	Not applicable
Niederer & Mueller (19)	8/11	High	Chronic LBP	1081	10 trials	>6 weeks	Inception to 1/10/2018
Saragiotto *et al.* (10)	11/11	High	Chronic LBP	2431	29 RCTs	>12 weeks	Inception to 04/2015
Smith *et al.* (21)	7/11	Moderate	LBP	NA	29 RCTs	Pain or stiffness between lower rib and buttock crease (studies with specific pathology were excluded)	10/2006 to 10/2013
Wang *et al.* (12)	8/11	High	Chronic LBP	414	5 RCTs	>3 months	1970 to 10/2011
Zhang *et al.* (22)	8/11	High	Chronic LBP	1333	18 RCTs	>12 weeks	Inception to 08/2020
Hayden *et al.* (17)	10/11	High	Chronic LBP	20,969	217 RCTs	>12 weeks	Not applicable
Searle *et al.* (20)	8/11	High	Chronic LBP	4462	45 RCTs	Pain and discomfort localized below the costal margin and above the inferior gluteal folds lasting more than 3 months	Inception to 30/10/2014
Zhang *et al.* (72)	7/11	Moderate	Chronic LBP	950	18 RCTs	Physician-diagnosed for more than 3 months	Inception to 01/05/2021

AMSTAR, Assessment of multiple sytematic reviews; RCT, randomized controlled trial; LBP, low back pain.

Table 2 Systematic reviews and meta-analyses investigating the effect of MCE on low back pain.

Source/intervention vs control	Outcomes				Result, MD (95% CI)	Interpretations							
	Scale	Duration	Sample size	Group number		Effect	P1	P2	Heterogeneity	I^2	Quality of evidence	Effect size	Other
Owen *et al.* (5)													
Stabilization vs no treatment													
Pain			1062	39	−1.31 (−1.75 to −0.87)*	Favors stabilization	**<0.001**						SUCRAs of 80%
Disability			1062	39	−1.13 (−1.53 to −0.74)*	Favors stabilization	**<0.001**						SUCRAs of 80%
Mental health			1062	39	−0.78 (−1.49 to −0.07)*	Favors stabilization	**0.031**						SUCRAs of 50%
Bernard *et al.* (25)													
PFMT + exercise vs exercise													
Pain	VAS		157	4	−0.61 (−0.91 to −0.31)	Favors MCE	**<0.0001**		Low	0%	Very low		
Disability	ODI		157	4	−0.87 (−3.21 to 1.46)	Comparable	0.46		High	77%			
Byström *et al.* (13)													
MCE vs general exercise													
Pain	0–100	6–16 wk	529	6	−7.80 (−10.95 to −4.65)	Favors MCE							
Pain	0–100	4–8 mo	523	3	−6.06 (−10.94 to −1.18)	Favors MCE							
Pain	0–100	8–15 months	632	4	−3.10 (−7.03 to 0.83)	Comparable							
Disability	0–100	6–16 wk	480	5	−4.65 (−6.20 to −3.11)	Favors MCE							
Disability	0–100	4–8 mo	523	3	−4.86 (−8.59 to −1.13)	Favors MCE							
Disability	0–100	8–15 mo	523	3	−4.72 (−8.81 to −0.63)	Favors MCE							
MCE vs spinal manual therapy													
Pain	0–100	6–16 wk	633	3	−1.32 (−6.30 to 3.65)	Comparable							
Pain	0–100	4–8 mo	586	2	−2.31 (−7.85 to 3.22)	Comparable							
Pain	0–100	8–15 mo	633	3	−0.43 (−5.47 to 4.62)	Comparable							
Disability	0–100	6–16 wk	633	3	−6.12 (−11.94 to −0.30)	Favors MCE							
Disability	0–100	4–8 mo	586	2	−5.27 (−9.52 to −1.01)	Favors MCE							
Disability	0–100	8–15 mo	633	3	−5.76 (−9.21 to −2.32)	Favors MCE							
MCE vs minimal intervention													
Pain	0–100	6–16 wk	500	2	−12.48 (−19.04 to −5.93)	Favors MCE							
Pain	0–100	4–8 mo	500	2	−10.18 (−16.64 to −3.72)	Favors MCE							
Pain	0–100	8–15 mo	500	2	−13.32 (−19.75 to −6.90)	Favors MCE							
Disability	0–100	6–16 wk	541	3	−9.00 (−15.28 to −2.73)	Favors MCE							
Disability	0–100	4–8 mo	500	2	−5.62 (−10.46 to −0.77)	Favors MCE							
Disability	0–100	8–15 mo	500	2	−6.64 (−11.72 to −1.57)	Favors MCE							
MCE vs multimodal PT													
Pain	0–100	4–8 mo	499	4	−14.20 (−21.23 to −7.16)	Favors MCE							
Disability	0–100	4–8 mo	656	2	−12.98 (−19.49 to −6.47)	Favors MCE							
Gomes-Neto *et al.* (24)													
STE vs general exercise													
Pain	0–10		603	8	−1.03 (−1.79 to −0.27)	Favors stabilization	**0.008**	<0.00001	High	86%			
Disability	ODI		209	5	−5.41 (−8.34 to −2.49)	Favors stabilization	**0.0003**	0.0002	High	82%			
Disability	RMDQ		310	2	−0.75 (−2.26 to 0.75)	Comparable effect	0.33	0.95	Low	0%			
STE vs manual therapy													
Pain	0–10		358	3	−0.38 (−0.98 to 0.22)	Comparable effect	0.22	0.75	Low	0%			
Disability			358	3	−0.17 (−0.38 to 0.03)*	Comparable effect	0.10	0.58	Low	0%			
Luomajoki *et al.* (18)													
MCE vs control intervention													
Pain		Post-treatment	541	9	−0.39 (−0.73 to −0.04)*	Favors MCE	**0.03**	0.23	Low	29%,			
Pain		12-mo FU	366	5	−0.27 (−0.62 to 0.09)*	Comparable effect	0.14	0.02	High	75%			
Disability		Post-treatment	642	11	−0.38 (−0.68 to −0.09)*	Favors MCE	**0.01**	0.47	Low	0%		Small	
Disability		12-mo FU	425	6	−0.37 (−0.69 to −0.04)*	Favors MCE	**0.03**	0.09	Moderate	58%		Small	
Macedo *et al.* (14)													
MCE vs other exercises													
Pain	0–100	0–3 mo	82	2	5.74 (−3.34 to 14.82)	Comparable effect	0.22	0.93	Low	0%	Moderate		
Pain	0–100	3–12 mo	33	1	−1.20 (−18.24 to 15.84)	Comparable effect	0.89				Low		
Disability	0–100	0–3 mo	116	2	−0.84 (−8.72 to 7.04)	Comparable effect	0.83	0.28	Low	15%	Moderate		
Disability	0–100	3–12 mo	33	1	−6.70 (−22.80 to 9.40)	Comparable effect	0.41				Low		

(*Continued*)

Table 2 Coninued.

Source/intervention vs control	Outcomes				Result, MD (95% CI)	Interpretations							
	Scale	Duration	Sample size	Group number		Effect	P1	P2	Heterogeneity	I^2	Quality of evidence	Effect size	Other
Disability	0–100	> 12 mo	83	1	5.70 (−1.38 to 12.78)	Comparable effect	0.11				Low		
MCE vs manual therapy													
Pain	0–100	0–3 mo	58	1	9.0 (−1.56 to 19.56)	Comparable effect	0.095				Low		
Disability	0–100	0–3 mo	85	1	4.0 (−3.38 to 11.38)	Comparable effect	0.29				Low		
Disability	0–100	>12 mo	85	1	3.70 (−4.10 to 11.50)	Comparable effect	0.35				Low		
MCE+MM vs MM													
Pain	0–100	0–3 mo	41	1	−9.3 (−20.41 to 1.81)	Comparable effect	0.10				Very low		
Disability	0–100	0–3 mo	41	1	−2.4 (−4.87 to 0.07)	Comparable effect	0.057				Very low		
Niederer *et al*. (23)													
MCE vs no additional exercise													
Current pain		3 wk	2137	17	−0.15 (−0.28 to −0.02)*	Favors MCE	**0.03**	0.02	Moderate	47%	Moderate	Larger	
Current pain		6 wk	1875	18	−0.15 (−0.24 to −0.06)*	Favors MCE	**0.002**	0.70	Low	0%	Moderate	Larger	
Current pain		6 mo	1692	16	−0.19 (−0.28 to −0.09)*	Favors MCE	**0.0002**	0.55	Low	0%	High	Larger	
Characteristic pain		3 wk	2137	17	−0.19 (−0.35 to −0.04)*	Favors MCE	**0.01**	0.0005	High	61%	Moderate	Larger	
Characteristic pain		6 wk	1835	17	−0.26 (−0.38 to −0.14)*	Favors MCE	**< 0.0001**	0.15	Low	27%	High	Larger	
Characteristic pain		6 mo	1692	16	−0.25 (−0.38 to −0.11)*	Favors MCE	**0.0003**	0.07	Moderate	36%	Moderate	Larger	
Disability		3 wk	2137	17	−0.24 (−0.33 to −0.15)*	Favors MCE	**<0.00001**	0.44	Low	1%	High	Larger	
Disability		6 wk	1835	17	−0.27 (−0.40 to −0.13)*	Favors MCE	**<0.0001**	0.04	Moderate	41%	High	Larger	
Disability		6 mo	1692	16	−0.25 (−0.39 to −0.11)*	Favors MCE	**0.0004**	0.04	Moderate	41%	Moderate	Larger	
Niederer & Mueller (19)													
MCE vs control intervention													
Pain			1210	13	−0.46 (−0.78 to −0.14)*	Favors MCE	**0.004**	<0.00001	High	86%	Low-to-moderate		
Disability			7311	12	−0.44 (−0.80 to −0.09)*	Favors MCE	**0.01**	<0.00001	High	88%	Low-to-moderate		
Saragiotto *et al*. (10)													
MCE vs other exercises													
Pain	0–100	0–3 mo	872	13	−7.53 (−10.54 to −4.52)	Favors MCE	**<0.00001**	0.05	Moderate	43%		Small	No clinical importance
Pain	0–100	3–12 mo	588	6	−2.98 (−6.96 to 0.99)	Comparable effect	0.14	0.90	Low	0%	High		
Pain	0–100	>12 mo	643	5	−2.69 (−6.90 to 1.53)	Comparable effect	0.21	0.76	Low	0%	High		
Disability	0–100	0–3 mo	794	11	−4.82 (−6.95 to −2.68)	Favors MCE	**<0.00001**	0.03	Moderate	50%	Low quality	Small	No clinical importance
Disability	0–100	3–12 mo	588	6	−2.88 (−6.92 to 1.15)	Comparable effect	0.16	0.58	Low	0%	High		
Disability	0–100	>12 mo	570	4	−0.71 (−4.87 to 3.45)	Comparable effect	0.74	0.81	Low	0%	High		
Mental health	0–100	0–3 mo	269	2	−0.75 (−3.33 to 1.83)	Comparable effect	0.57	0.62	Low	0%	Moderate		
MCE vs manual therapy													
Pain	0–100	0–3 mo	282	3	−4.36 (−9.52 to 0.81)	Comparable effect	0.098	0.55	Low	0%	Moderate		
Pain	0–100	3–12 mo	485	4	−7.05 (−14.20 to 0.11)	Comparable effect	0.054	0.08	Moderate	55%	Moderate		
Pain	0–100	>12 mo	406	4	−3.67 (−9.28 to 1.94)	Comparable effect	0.20	0.64	Low	0%	High		
Disability	0–100	0–3 mo	282	3	−2.79 (−6.60 to 1.02)	Comparable effect	0.15	0.69	Low	0%	Moderate		
Disability	0–100	3–12 mo	485	4	−3.28 (−6.97 to 0.40)	Comparable effect	0.08	0.41	Low	0%	High		
Disability	0–100	>12 mo	406	4	−3.40 (−7.87 to 1.07)	Comparable effect	0.14	0.79	Low	0%	High		
MCE vs minimal intervention													
Pain	0–100	0–3 mo	291	4	−10.01 (−15.67 to −4.35)	Favors MCE	**0.00053**	0.19	Moderate	37%	Moderate	Medium	Clinically important
Pain	0–100	3–12 mo	348	4	−12.61 (−20.53 to −4.69)	Favors MCE	**0.0018**	0.08	Moderate	56%	Low	Medium	Clinically important
Pain	0–100	>12 mo	279	3	−12.97 (−18.51 to −7.42)	Favors MCE	**<0.00001**	0.95	Low	0%,	Moderate-	Medium	Clinically important
Disability	0–100	0–3 mo	332	5	−8.63 (−14.78 to −2.47)	Favors MCE	**0.0060**	0.004	High	74%	Very low	Small	No clinical importance
Disability	0–100	3–12 mo	348	4	−5.47 (−9.17 to −1.77)	Favors MCE	**0.0038**	0.25	Low	28%	Moderate	Small	No clinical importance
Disability	0–100	>12 mo	279	3	−5.96 (−9.81 to −2.11)	Favors MCE	**0.0024**	0.39	Low	0%	Moderate	Small	No clinical importance
MCE vs exercise+EP agents													
Pain	0–100	0–3 mo	68	2	−30.18 (−35.32 to −25.05)	Favors MCE	**<0.00001**	0.44	Low	0%	Low	Large	Clinically important

(*Continued*)

Table 2 Coninued.

Source/intervention vs control	Outcomes				Result, MD (95% CI)	Interpretations							
	Scale	Duration	Sample size	Group number		Effect	P1	P2	Heterogeneity	I^2	Quality of evidence	Effect size	Other
Pain	0–100	3–12 mo	179	2	−19.39 (−36.83 to −1.96)	Favors MCE	**0.029**	0.029	High	95%	Very low	Small	No clinical importance
Smith *et al.* (21)													
MCE vs control intervention													
Pain	0–100	0–3 mo			−7.93 (−11.74 to −4.12)	Favors MCE†			High	67%	High		No clinical importance
Pain	0–100	3–12 mo			−6.10 (−10.54 to −1.65)	Favors MCE†			Moderate	50%	High		No clinical importance
Pain	0–100	> 12 months			−6.39 (−10.14 to −2.65)	Favors MCE†			Moderate	45%	High		No clinical importance
Disability	0–100	0–3 mo			−3.61 (−6.53 to −0.70)	Favors MCE†			High	83%	High		No clinical importance
Disability	0–100	3–12 months			−2.31 (−5.85 to 1.23)	Comparable effect			High	65%			
Disability	0–100	> 12 mo			−3.92 (−7.25 to −0.59)	Favors MCE†			Moderate	56%	High		No clinical importance
Wang *et al.* (12)													
MCE vs general exercise													
Pain	0–10	0–3 mo	290	4	−1.29 (−2.47 to −0.11)	Favors MCE	**0.03**	0.0002	High	85%			
Pain	0–10	>12 mo	284	3	−0.32 (−0.87 to 0.23)	Comparable effect	0.25	0.60	Low	0%			
Disability	ODI	0–3 mo	256	4	−7.14 (−11.64 to 2.65)	Favors MCE	**0.002**	0.0007	High	82%			
Zhang *et al.* (22)													
MCE vs other treatments													
Pain		Post-treatment	1489	20	−0.43 (−0.66 to −0.20)*	Favors MCE	**0.0003**	<0.00001	High	76%	Very low	Small	
Pain		6-mo FU	826	6	−0.18 (−0.32 to −0.04)*	Favors MCE	**0.01**	0.32	Low	14%	Moderate	Small	
Pain		12-mo FU	802	7	−0.08 (−0.22 to 0.06)*	Comparable effect	0.25	0.69	Low	0%	High		
Pain		24-mo FU	802	7	−0.25 (−0.61 to 0.11)*	Comparable effect	0.18	0.26	Low	20%	Low		
Disability		Post-treatment	1437	19	−0.39 (−0.64 to −0.13)*	Favors MCE	**0.003**	<0.00001	High	80%	Very low	Small	
Disability		6-mo FU	826	6	−0.13 (−0.26 to 0.01)*	Comparable effect	0.08	0.43	Low	0%	High		
Disability		12-mo FU	820	6	−0.13 (−0.27 to 0.01)*	Comparable effect	0.07	0.98	Low	0%	High		
Disability		24-mo FU	126	2	−0.11 (−0.47 to 0.24)*	Comparable effect	0.53	0.60	Low	0%	Very low		
Hayden *et al.* (17)													
CS vs minimal treatment													
Pain	0–100		2476	61	−13.4 (−17.2 to −9.6)	Favors CS;							No clinical importance
Disability	0–100		2320	56	−6.6 (−9.0 to −4.3)	Favors CS;							No clinical importance
Searle *et al.* (20)													
STE vs other interventions													
Pain			1343	12	−0.47 (−0.77 to −0.18)*	Favors stabilization†		< 0.01	High	83.2%		Small	
Zhang *et al.* (72)													
CST vs control intervention													
Pain			144	4	−0.89 (−1.94 to 0.16)*	Comparable effect	0.1		High	88%			

*P*1 values in bold indicate significant effect. *P*1 indicates difference of outcomes and *P*2 indicates differences in heterogeneity between intervention and control groups.
*Values are standard mean difference (95% CI); †indicates significant effect.
CS, core strengthening; CST, core strength training; EP, electrophysical; MCE, motor control exercise;MM, medical management; mo, months; ODI, Oswestry Disability Index; PFMT, Pelvic floor muscles training; PT, physical therapy; RMDQ, Roland-Morris Disability Questionnaire; STE, stabilization exercise; SUCRA, surface under cumulative ranking; VAS, visual analogue scale; wk, weeks.

(12, 18, 21, 22). Notably, although the effect size of these superiorities varied from small to large, of which some were not clinically important, the positive effects of MCE were consistent. Meanwhile, a prospective meta-analysis indicated that MCE could relieve current pain and characteristic pain intensity for patients with CLBP, and the effectiveness was sustainable for a long term based on low-to-moderate heterogeneity (23). Moreover, meta-analyses with moderate-to-high quality demonstrated that MCE was as effective as manual therapy for LBP-related symptoms, and the results were highly consistent (10, 24), whereas one study reported further effectiveness of MCE on disability (13). Only one research discovered the effectiveness of MCE on mental health compared to no treatment, which indicates its positive effect on mental health, with a surface under the cumulative ranking of 50% (5).

In the comparison between MCE and general exercise, the superiority of MCE has also been demonstrated in pain and disability reduction for patients with CLBP (10, 13, 24). A similar finding indicated that the long-term effect may be not as significant as the short-term effect (10, 13). In addition, MCE was more effective than aerobic and stretching exercises in pain relief and more helpful than stretching in disability improvement based on a network meta-analysis (17). A high-quality study focusing on the additional effect of pelvic floor muscle training (PFMT) indicated that patients undergoing exercise plus PFMT reported reduced LBP and similar dysfunction compared with those receiving single exercise (25). Considering its evident effectiveness, MCE ranks as the second and first option for treating pain and disability, respectively, with SUCRA of 80% (5). As for mental health, a moderate-quality evidence with low heterogeneity concluded that MCE was as effective as other exercises (10).

Weaken deep core muscle is one of the typical symptoms of LBP patients. A regular MCE training program has been proven to significantly improve the recruitment of transversus abdominis (26). MCE could demonstrate better pain-relieving effectiveness, especially in patients with impaired transversus abdominis activation. Therefore, a pre-diagnose through ultrasonography examining the recruitment of transversus abdominis might provide clues for clinicians to make MCE prescriptions (26). Moreover, patients with the intermediate intensity of LBP (2–2.5/11) could obtain more benefits from MCE than other patients, and the effectiveness of MCE was possibly higher for older patients than the younger ones in patients aged from 35 to 50 (23). Besides, the MCE lasting more than 8 weeks may be more important for pain reduction (25). Therefore, MCE intervention lasting for a longer duration could be recommended for patients with acute, sub-acute, or CLBP, especially those who are older or with intermediate pain intensity.

Mechanisms

The underlying improvement mechanisms of MCE on LBP from brain, biochemistry, inflammatory, and neuromuscular aspects are illustrated in Fig. 1.

Brain

The concept ‘body map’ concluded that every part of the body is represented by a neuron network in the brain, especially in the primary somatosensory cortex (S1) (27, 28). ‘Body map’ is dynamically maintained, as it may expand or contract according to the representation extent of certain body regions. Research has found pain, movement impairment, and neglect of certain body parts could disturb and weaken the representation of S1. Meanwhile, the S1 representation extent is found to be correlated with more pain, even hyperalgesia (29). That is, pain might be a cause and consequence of ‘body map’ alternation simultaneously. To elaborate, peripheral pain in low back regions could trigger the alternation of S1 representation, which lead to further central-related pain. Additionally, pain and fear avoidance could result in the decrease of spinal movement and the neglect of low back areas, which could further weaken the representation, thereby aggravated pain. These two vicious cycles were interactive, and they might account for the transition from acute to chronic. An fMRI research indicated the regions in S1 and primary motor cortex (M1) topographically representing the core muscles were activated during MCE, indicating the remapping function (30). Therefore, MCE could re-activate deep trunk muscle, improve lumbar spine proprioception and increase sensory input which helps to retain the normal representation in corresponding brain regions, therefore breaking the vicious cycle.

In terms of brain structural alternation, the present research has revealed the differences between CLBP patients and normal people (31, 32). Decreased white matter in corpus callosum and internal capsule was found in CLBP patients. Meanwhile, less gray matter in the temporal lobe, dorsolateral prefrontal cortex (DLPFC), insula, and S1 was revealed (32, 33), most of which was related to the pain matrix (34). As a common exercise form to improve muscular strength and size, resistance training (RT) has been reported to reduce self-reported pain in LBP patients (35). Some research has found an association between skeletal muscle hypertrophy and increasing whole white matter volume, as well as the gray matter volume in the right temporal lobe (36). Moreover, RT was proven effective in alleviating white matter atrophy during age degeneration among the elderly (37, 38). Considering similar muscle contraction during MCE, the alleviating mechanism of MCE on LBP might be identical to RT.

As for brain activity, the functional connectivity in medial prefrontal cortex, cingulate cortex, insula, and S1 increased during resting state in CLBP patients compared with that in the normal population, implying the risks of brain overreaction toward innoxious stimuli (32). Meanwhile, increased activity in S1, S2, posterior cingulate cortex, and insula following mechanical pain stimuli was found, indicating an amplifying nociceptive signal within multiple brain regions (32). Increased activation of these regions evidenced an upregulated pain sensitivity pattern among CLBP patients. Exercise has been proven to alter brain activity. A 26-week RT program could decrease the functional connectivity in the anterior cingulate cortex (ACC) during the resting state (38, 39). When coping with painful stimulation, people with regular exercise habits demonstrated a significantly reduced activation in S1, insula, ACC, and DLPFC compared to those without (40). In summary, MCE might be specifically effective for LBP patients as its function in brain remapping. Furthermore, its significance in reversing brain structural maladaptation and altering brain activation mode might also benefit LBP patients, especially chronic ones.

Biochemistry

The possible mechanism of pain reduction is exercise-induced hypoalgesia (EIH) induced by MCE. EIH is the phenomenon where exercise decreases sensitivity to pain stimuli, indicating hypoalgesia during and following exercise (41). The mechanisms of EIH were not clearly revealed, but some possible ones have been proposed (42). First, exercise can increase the emission of β-endorphins that could bind with opiate receptors in peripheral and central regions. Regions with a higher level of opioid receptors were more frequently regulated compared to other regions, such as insula and descending pain inhibitory pathways (ACC, PAG) (43). Given that these regions were responsible for emotion and pain modulation, β-endorphins might be effective in alleviating pain and improving mood. Among patients with CLBP, the β-endorphin level has been proven to elevate after MCE, indicating the analgesia effect of MCE mediated by endogenous opioid system (44). Endocannabinoid (eCB), as a non-opioid substance, was also indispensable in EIH. The analgesic effect was initiated by upregulating the level of eCB, such as *N*-arachidonylethanolamine and 2-arachidonoylglycerol, in the circulation system, thereby activating CB_1 (Type-1 cannabinoid receptors) and regulating CB_1 sensitivity within pain-related brain regions and spinal cord (45, 46). The exogenous activation of CB receptors resulted in EIH. Exercises in different movement patterns, including RT, aerobic exercise, and Tai Chi, have been proven effective in modulating eCB (47, 48).

Research that discovered characteristics of EIH has reached some conclusions. For example, the EIH effect could vary based on different exercising parts. Specifically, the exercising body part generates a larger EIH effect than

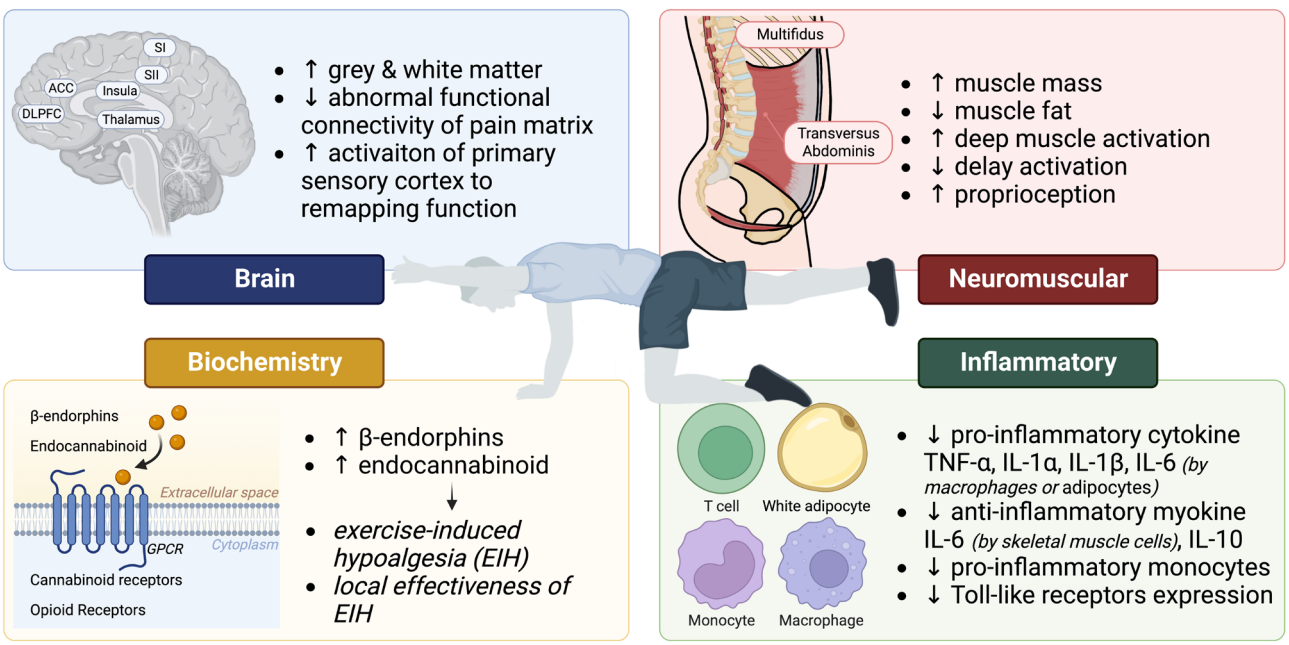

Figure 1

The underlying improvement mechanisms of MCE on LBP from brain, biochemistry, inflammatory, and neuromuscular aspects. SI, primary somatosensory cortex; SII, secondary somatosensory cortex; DLPFC, dorsolateral prefrontal cortex; TNF-α, tumor necrosis factor alpha; IL-1α, interleukin 1α; IL-1β, interleukin 1β; IL-6, interleukin 6.

regions which are away from the exercising part (49). Based on this finding, MCE might be considered superior since its 'local effectiveness' in inducing hypoalgesia for patients with LBP. More high-quality research is needed to comprehensively explore the EIH effectiveness induced by MCE.

Inflammatory

Large proportion of research has focused on the inflammation pathogenesis of intervertebral disc degeneration, which was a main contributor to LBP (50). The events initiating inflammatory responses could be a genetic predisposition, acute trauma, or chronic overload (51). In a pathological circumstance, nucleus pulposus and annulus fibrosus cells abnormally produce pro-inflammatory molecules, including cytokines TNF-α, IL-1α, IL-1β, and IL-6 (52, 53). These molecules promote extracellular matrix degradation and recruitment of immune cells to the discal tissues (54).

The exercise-induced anti-inflammatory effects have been proposed by many researchers, which could be explained by multiple mechanisms (55, 56). Adipokines, such as TNF-α, have been mentioned previously as key factors for the development of inflammatory in LBP (57). Regular exercise could decrease fat mass through physical consumption and reduce adipokine emission. A moderate exercise program lasting for 6 months was proven to significantly reduce TNF-α levels (58). Besides, skeletal muscle, as an organ with endocrine function, could form an anti-inflammatory environment by releasing anti-inflammatory myokines (IL-6) through muscle contraction. The predominant role of IL-6 acts as an anti-inflammatory myokine by mediating the emergence of IL-1 receptor antagonist and IL-10 in circulation, thereby inhibiting the generation of inflammatory factors (59, 60, 61). In addition, exercise could decrease the expression of Toll-like receptors on macrophages, which accounted for the signaling of pro-inflammatory mediators (62). Meanwhile, decreased pro-inflammatory monocytes (CD14+ and CD16+) and increased regulatory T cells within the circulatory system were found after exercise (56).

Currently, few studies have specifically observed the specific effect of MCE on LBP from an inflammatory aspect. One research investigated the plasma concentration level changes of TNF-α and IL-6 after long-term MCE intervention among patients with LBP (63). Their results indicated TNF-α maintained whereas IL-6 increased after intervention. That is, MCE could not only prevent further generation of inflammatory factors but also contribute to an increase in anti-inflammatory factors, which inhibits the inflammatory process. Additional research is needed to verify the anti-inflammatory mechanisms of MCE.

Neuromuscular

The deep trunk muscles are attached to the thoracolumbar fascia, which can increase the stiffness of the tissue, thereby improving core stability and resisting pressure on joints (64). Normally, these muscles will be activated prior to superficial muscles to maintain core stability during daily activities. During pathological circumstances, they became dysfunctional whereas superficial ones were recruited for obtaining more spinal stability. Subsequently, patients with CLBP exhibited co-activation of agonistic and antagonistic muscles in the superficial layer (65). The emergence of this compensation mode is actually another body strategy to minimize lumbar spine instability. This abnormal activation strategy might be effective in the short term. With regard to the long term, the chronic stiffening of agonists and antagonists is identical with the mechanisms of muscle spasm, which may induce further pain related to spasticity, even neuropathic pain (66). By targeting deep trunk muscles, MCE is sufficient in adjusting incorrect activated mode by improving the strength of weak deep core muscles (67). An adequate stability provided by a strengthened core could be a signal for the brain to redefine an optimal activation pattern, instead of a co-activated and physical-demanding one.

Another feature of CLBP patients with regard to abnormal activation is the delayed response to external perturbations (68), which is a factor for injury as longer reaction time is needed for deep core muscles to be physically engaged. Soft tissues damaged by previous injury might account for the deficits in proprioceptive and nociceptive receptors, which postpones the reflex responses, thereby leading to untimely muscle activation (65). As MCE can decrease motion error and retain normal proprioception (67), repeated training on core muscles effectively stimulates muscle spindles and receptors, thereby improving sensorimotor integration.

In terms of morphology, higher intramuscular fat percentage in multifidus was found among patients with CLBP than that in the healthy population (69). Similarly, the cross-sectional area of multifidus and paraspinal muscles was decreased compared with that of normal people (70). All of the morphological alternations earlier result in impaired strength, inadequate endurance, and progressive vulnerability of deep core muscles. A lasting MCE program could result in a lower proportion of intramuscular adipose tissue (71), along with exercise-induced hypertrophy in low back muscles (67). Therefore, MCE can effectively avoid abnormal compensation, shorten reaction time, increase multi-dimensional sensory input, prevent negative morphological transformation, and reconstruct body postures in the aspect of neuromuscular.

Conclusion

This review summarized the clinical effectiveness and the mechanism of MCE in relieving LBP-related impairments. MCE is effective in alleviating pain and improving disability. Multiple mechanisms from the aspects of brain, biochemistry, inflammatory, and neuromuscular simultaneously contribute to its efficacy. MCE could remap brain representation and reverse the negative brain alternation, induce EIH to relieve pain, mediate anti-inflammatory response, retain normal activation mode, and improve morphological deficits. Although MCE has demonstrated its superiority within multiple exercise therapies for LBP, a deeper understanding is limited but indispensable. This study is instructive for future LBP treatments and provide more information for clinicians when making exercise prescriptions. Additional clinical research that specifically describes the underlying mechanism targeted MCE is needed.

ICMJE conflict of interest statement
The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

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Data availability
The data used to support the findings of this study are available on request from the corresponding author.

Author contribution statement
Y-LZ conceived the review. H-RX and Y-HZ drafted the manuscript and searched the literature to identify eligible trials. H-RX and Y-HZ extracted and analyzed data. All authors approved the final manuscript.

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