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Does the performance of five back-associated exercises relate to the presence of low back pain? A cross-sectional observational investigation in regional Australian council workers

Charles Philip Gabel,[1] Hamid Reza Mokhtarinia,[2] Jonathan Hoffman,[3] Jason Osborne,[4,5] E-Liisa Laakso,[6,7] Markus Melloh[8,9,10]

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For numbered affiliations see end of article.

Correspondence to
Dr Charles Philip Gabel; cp.gabel@bigpond.com

ABSTRACT

Objectives Investigate the relationships between the ability/inability to perform five physical test exercises and the presence or absence of low back pain (LBP).
Setting Regional Australian council training facility.
Participants Consecutive participants recruited during 39 back education classes (8–26 participants per class) for workers in general office/administration, parks/gardens maintenance, roads maintenance, library, child care and management. Total sample (n=539) was reduced through non-consent and insufficient demographic data to n=422. Age 38.6±15.3 years, range 18–64 years, 67.1% male.
Methods Cross-sectional, exploratory, observational investigation. LBP presence was ascertained from a three-response option questionnaire: 0=none/rarely (no) 1=sometimes (some), 2=mostly/always (most). Statistical correlation was performed with the number of the five test exercises the individual successfully performed: (1) extension in lying: 3 s; (2) 'toilet squat'; feet flat, feet touched: 3 s; (3) full squat then stand up: 5 times; (4) supine sit-up, knees flexed: 10 times; and (5) leg extension, supine bilateral: 10 times.
Interventions Nil.
Results For the group 'no-some', 94.3% completed 4–5 test exercises, while for group 'With', 95.7% completed 0–1 test exercises. The relationship between LBP presence and number of exercises performed was highly significant ($\chi^2_{(10)}$=300.61, p<0.001). Furthermore, multinomial logistic regression predicting LBP (0=no, 1=some, 2=most) from the number of exercises completed, substantially improved the model fit (initial-2LL=348.246, final-2LL=73.620, $\chi^2_{(2)}$=274.626, p<0.001). As the number of exercises performed increased, the odds of reporting 'some LBP' or 'most LBP' dropped substantially (ORs of 0.34 and 0.17, respectively).
Conclusion The ability to complete/not complete five test exercises correlated statistically and significantly with a higher LBP absence/presence in a general working population. Training individuals to complete such exercises could facilitate reductions in LBP incidence; however, causality cannot be inferred. Randomised trials are recommended to establish the potential efficacy of exercise-based approaches, considering these five selected exercises, for predicting and managing LBP.

Strengths and limitations of this study

- ► The sample diversity with continuity and subsequent homogeneity enabled generalisation to be inferred.
- ► This was a cross-sectional, exploratory, observational investigation.
- ► It is representative of a general working population as it contained diverse occupations, ages, both genders and a consecutive sample from regional council workers during an educational workshop.
- ► The sample size was sufficient to ensure adequate power.
- ► The functional exercises were not tailored for either dose or specificity for age or gender.

INTRODUCTION

Low back pain (LBP) is among the world's most prevalent occupational disorders in working populations[1] and major global public health concerns[2 3] and worsening due to increasing age and populations.[4] It affects 12% of the world's population at any given time[2 5] with lifetime prevalence at 84% and chronicity around 23%.[2] When disability-adjusted life years are considered, LBP is a leading global cause of disease burden.[5 6] LBP is distinctive in that limited progress has occurred in identifying effective prevention strategies and treatments[7 8] and remains nearly impossible to provide absolute certainty of a specific nociceptive cause, and only a small proportion has a recognised pathological cause.[3 6] This is despite established recognition and identification of factors that predispose or correlate to future LBP.[6 9 10] Predicting problematic LBP has several promising protocols including questionnaire-based biopsychosocial screening methods[11–13] and movement patterns or maladaptive postures.[14] There are, however, few or no validated physiological or physical predictive screening tests[15] including measures of disuse or changed levels of physical conditioning.[16]

The LBP economic burden leads to reduced efficiency and productivity by individuals, organisations and the community compounding direct or indirect costs to private, professional and governmental medical care stakeholders, wages compensation, worker recruitment and training and productivity losses.[5 17] These factors are further inflated by social consequences to individuals, families, communities and general society.[18 19] Despite many recognised risk factors that predispose individuals to LBP,[10 20] business process trends in work settings coupled with recent technology advancement have seen occupational and social changes that influence the requirements or personal choices to adopt static postures.[21] In contrast, manual workers have gained both advantages and disadvantages, with occupational postures and loads in areas such as maintenance and building having remained consistent.[14 22]

The direction of contemporary research on LBP prevention and recurrence has focused on non-modifiable factors and long-term exposures. These include: medical investigative relationships such as radiological[23 24] or physiological findings[25–27] that have produced mixed results even from the same study[28] and biopsychosocial considerations[29–32] or a mixture of these.[9–11] In contrast, modifiable factors[33 34] including movement patterns,[14 35] physiological loads[36] and exercise capacity[37 38] receive limited attention yet they significantly influence LBP morbidity and symptomology,[1 2] being recognised as potentially able to prevent LBP.[11 20]

LBP disorders are multifactorial with individual symptomology influenced by various pathoanatomical, physical, neurophysiological, psychological and social contributors.[3 14 36] Consequently, voluntary activities that involve lumbopelvic-specific exercises are effective in primary and secondary LBP prevention.[39] Such exercises improve fitness and occupational status by diminishing disability and problem severity[35 40] and may counter selective atrophy of type II fibres found in the presence of pathological changes.[41 42] However, muscle recruitment remains predominantly neural based during rehabilitation with psychological adaptations derived from improved motivation and pain tolerance.[43] The conundrum remains that LBP reduces functional capacity, fitness and general health status (GHS), including depression,[44] while low capacity from pathology, injury, GHS or sedentary lifestyle increases the risk of LBP.[45] The need to consider modifiable factors is supported by recent research[46] that confirmed the relationship between dynamic physical tests, self-reported LBP and reduced function.[38 47]

Existing research has a knowledge gap for modifiable factors demonstrating a need for observational studies in representative working populations.[3 6 11] Addressing this gap will assist in identifying the relationship between LBP symptoms and individual physical functional movement capabilities. A representative group, with strong indicators of generalisability, is council workers. The group includes diversity of gender, age and occupations with variance in manual and sustained loads[48] and stationary and sedentary postures.[49] Cross-sectional analysis of these groups is a starting point in implied generalisation and provides insight into the capacities and abilities that may lead to the presence or risk of LBP.[50 51]

This observational study investigated council workers, as an implied representative general working population sample and evaluated whether the ability, or not, to perform five back-related exercises could determine or predict the presence or absence of LBP. We hypothesised that the test exercises would demonstrate the ability of the lumbar spine to: move in a controlled manner through normal range as a complex multisegmental functional activity with coordinated biomechanical and neuromuscular components and be stabilised, as part of the lumbo-pelvic-hip complex, through motor control of the integrated muscular system.[36 52] Consequently, the ability to perform the exercises would correlate with lower self-reported LBP.

Once established, analysis of the findings might indicate what movements, or lack thereof, might be associated with the presence and/or absence of LBP for individuals in different occupational and physical activity settings. The outcomes might contribute to understanding the relevance of functional movement and exercises in relation to LBP and provide a direction for future prospective studies. Such studies could identify specific functional movements for specific tasks or risk groups, then provide structured exercise regimens that might reduce LBP and its predisposition.

METHODS

A cross-sectional, exploratory, observational investigation was initiated over a period of 28 months in a population of employees with the Sunshine Coast Regional Council in Queensland, Australia. Workers from a convenience sample were consecutively recruited during 39 annual back educational programme classes of 2-hours duration. The first two classes provided a pilot study (n=33) to estimate effect size, and 'Bootstrap analysis' ensured the effect size had reasonable confidence. Standard power estimation calculations on the range of anticipated effect sizes provided minimum sample size goals. The participants were recruited from a range of occupations, ages and work locations to provide participants that reasonably reflected the population of interest. This representative population minimised selection bias; however, potential bias remained from non-response, the volunteer consent requirement and ascertainment bias. Most participants were classified in to 21 occupational categories with an additional 'Other' category for miscellaneous non-specified occupations. Class participant numbers ranged from 8 to 26, with a total sample of n=539. Only participants who consented were included. Data were excluded if there was insufficient demographic information. Consequently,

Table 1 Sample demographics

Occupation (job)	Total	% Total	Male	% Total	% Male
Age (years)	38.6±15.3	Range: 18–64			
Archives	10	2.4	4	0.9	40.0
Airport maintenance	3	0.7	3	0.7	100.0*
Child care	36	8.5	3	0.7	7.5†
Community services	34	8.1	1	0.2	3.3†
Construction	22	5.2	22	5.2	100.0*
Corporate records	7	1.7	2	0.5	28.6†
Emergency room	21	5.0	15	3.6	71.4*
Fleet and plant	16	3.8	16	3.8	100.0
Information systems	5	1.2	2	0.5	40.0
Information technology	11	2.6	9	2.1	81.8*
Infrastructure	12	2.8	8	1.9	66.7
Library	46	10.9	15	3.6	32.6†
National parks	13	3.1	12	2.8	92.3*
Operations maintenance	7	1.7	6	1.4	85.7*
Operations management	11	2.6	7	1.7	63.6
Parks bushland services	69	16.4	68	16.1	98.6*
People and organisational	1	0.2	0	0.0	0.0†
Roads management	65	15.4	64	15.2	98.5*
Strategy and planning	11	2.6	7	1.7	63.6
Treasury and risk	2	0.5	2	0.5	100.0*
Water services	18	4.3	17	4.0	94.4*
Other	2	0.5	0	0.0	0.0†
Total	n=422	100.0	Male=283	Male=67.1	

*Indicates male >67%.
†Indicates female >67%.

the sample was reduced to a total of n=422, age 38.6±15.3 years, range 18–64 years, 67.3% male (see table 1). Males were predominant in manual occupational roles including maintenance and construction, while females were predominant in carer and resource management including child care, community services, library services and records roles.

Test activities

The test exercises were selected based on having significant elements of lumbo-pelvic-hip function and being recognised for reducing symptomology or risk of LBP. The five selected exercises were chosen to represent a balanced variation of functions required for normal daily activities.[35] Three exercises previously investigated, ‘repeated sit-ups’, ‘repeated squats’ and ‘extension in lying’ (EIL),[38] showed a positive correlation with LBP prevention and were consequently included. The sustained squat and leg extension exercises, respectively, require functional movement[36 52] and a predominantly isometric abdominal coactivation,[53] which occur or simulate daily occupational and sports activities.[54] Other exercises were considered but excluded, such as active spine flexion, which has shown poor correlation with LBP.[55]

All participants were volunteers and performed five functional movement exercises during an educational session with other attendees, supervised by the session leader, a sports physiotherapist certified in McKenzie Manual Diagnostic Therapy. The instructions for exercise justification, instructions, completion and reliability are detailed in table 2. Intraobserver reliability for screening tests movement instruction is recognised as being moderate to high.[56]

Questionnaire

During the educational sessions each participant completed a self-report questionnaire: ‘How often do you have low back pain?’ with three response options: ‘rarely/none’, ‘sometimes’ or ‘always/mostly’, with the time frame and symptoms interpreted within their life context. This three-point scale is condensed from the WHO’s five points: ‘never’, ‘rarely’, ‘sometimes’, ‘often’ and ‘very often’.[57] The central three-point response provides an ‘intermediate’ option, which is critical from

Table 2 Test activities: exercise descriptor and reliability

Test #	Title	Justification for inclusion	Instructions to participants	Successful completion	Test reliability
1	EIL: Extension in lying, held for 3 s	Maximal lumbar extension simulates the physical properties of normal spinal movements[36 79] because limited extension[80] is related to low back pain (LBP),[81] clinically impaired spinal control[82] and may inhibit symptom centralisation.[83 84]	Lying face down, hands beneath shoulders, forehead on the floor. Keep your pelvis on the floor, breathe in, press with your arms, raise your chest off the ground, breathing out and increasing the movement until your arms are straight. Hold for 3 s.	Hips/pelvis remains in contact with floor, arms fully extended.	ICC=0.95–0.98.[85]
2	SITUP: sit-up from supine, performed 10 times	Through range, active concentric and eccentric trunk flexion control enables the lumbar spine to dissipate and distribute load and provides a stable area for performing limb and trunk activities.[14 36 86 87]	Lying face-up on the floor, knees bent, feet flat, arms straight and hands on thighs. Breathe in, slowly sit up while breathing out, move the elbows to touch your knees, rolling forward and up from the floor in a continuous movement, until everything above the buttocks is not touching the ground and your elbows reach your knees. Lower down in a continuous movement without falling or dropping while breathing out. Repeat 10 times.	No sudden/rapid inertial motion, trunk not held rigid, feet remain on floor, elbows reach/pass the knees, body does not drop down.	ICC=0.995.[88]
3	LEGEXT: supine bilateral leg extension performed 10 times	Abdominal muscles are used predominantly isometrically to stabilise the body during this exercise[53 89] and relevant to performing many household, occupational and sports activities.[54] The exercise provides coactivation significantly greater than in sit-ups/curl,[90] enabling testing of rectus abdominis muscle and the internal and external oblique muscle activation[53] reducing LBP risk when part of a motor control exercise programme.[91]	Lying on back on floor breathing in, head in contact or elevated, knees bent and above the umbilicus, lower back contacts the floor, hands by side or under buttocks. Both legs are straightened, knees straightening until heels touch floor while breathing out. Small amounts of knee flexion are permitted. Return legs to the start position. Repeat 10 times.	Back and buttocks contact the floor, heels touch the ground, hands remain in start position.	(double) leg lower (ICC=0.81–1.00)[54] ICC=0.98[92]; active single leg raise $ICC_{3,3}$=0.95–0.97[93]; abdominal muscle % 'time active' is 54%–86%.[53]
4	SQUAT: 'toilet squat' barefoot, hands touch feet, held for 3 s	Squatting is frequently used and associated with many activities of daily living. It requires optimal lumbar flexion control to ensure normal spinal movements are maintained,[36 79] and shear forces/lateral movement are minimalised.[94] Squatting is a complex multisegmental functional movement requiring coordinated biomechanical and neuromuscular components involving the leg and pelvic joints and muscles, respiratory system, with prime-mover muscle activation not significantly affected by common variations in kinetic chain continuity.[95] A semirigid spine eliminates planar motion but retains anteroposterior spinal integrity, as spinal flexion generally increases with hip flexion and the associated synergistic lumbar-pelvic action,[94 96] which reduces the risk of LBP.[97]	Standing comfortably, feet shoulder-width apart, arms loosely at your side. Breathe in, slowly squat, as though using a squat-toilet, allow the arms to move forward and hands touch the feet. Hold for 3 s.	Pelvis is lowered, heels/feet flat, fingers touch the feet.	Intrarater kappa=0.81–1.00 when tested alone[98]; ICC >0.60 within a multiexercise screen[99] and ICC=0.81.[100]
5	RISEUP: full squat and stand-up, performed five times	Repeated squatting is functional and readily transfers to multiple ADLs. It requires coordinated prime-mover muscle activation and endurance[95] being the technique of choice for manual handling as net moments, muscle forces and internal spinal loads related to compression and shear force are reduced.[101] Reduces LBP risk and is critical for normal spinal movement.[36 79]	Complete the squat position described, then rise to full standing with the head rising at the slightly before or at the same time as the buttocks. Repeat five times; a short rest is permitted.	Full squat action as above; on rise trunk rises before buttocks/pelvis, that is, knee extension before hip.	ICC=0.61–0.80, SE of measurement <3%.[102]

psychological and statistical perspectives. Psychologically, three cognitive perspectives facilitate response accuracy by reducing cognitive load,[58 59] which improves precision and consistency.[60] Statistically, responses were coded on a 0–1–2 scale[61 62]: 0=rarely/none (no LBP), 1=sometimes (some LBP) and 2=always/mostly (most LBP).

Statistical analysis was performed using SPSS V.23.0 for Windows with significance set at $p<0.05$. Following preliminary data screening to ensure data quality (eg, no aberrant values), an initial cross-tabulation of LBP (0=none, 1=some, 2=most) and number of exercises was performed to explore whether self-reported LBP was related to the number of exercises completed. A χ^2 test evaluated whether the null hypothesis (that the number of exercises completed would be consistent across LBP groups) was tenable or able to be rejected. Standard power calculations on the effect sizes verified that the minimum sample size was exceeded.

A multinomial logistic regression was performed, exploring whether the number of exercises (EX_SUM) predicted LBP (categorised as 0, 1 and 2) to test the null hypothesis that the probability or odds of being classified into LBP groups are not different because of number of exercises performed and, if rejected, to quantify the change in odds or probability of LBP as it relates to number of exercises performed. This test also allowed us to evaluate whether participant gender interacted with EX_SUM, or whether there were non-linear effects present. Regression diagnostics for this analysis (eg, residuals and influence) were examined to ensure no aberrant cases were inappropriately influencing the analysis.[63] None were identified.

Finally, if the null hypothesis from the prior multinomial logistic regression was rejected, we performed a second multinomial logistic regression on LBP entering each exercise as a predictor (rather than simply the count of number of exercises completed) to examine whether all exercises were uniquely predictive or whether some subset of exercises were more predictive than others. All five exercises were entered simultaneously, allowing for examination of unique effects of each variable controlling for all other variables in the equation. Regression diagnostics were examined, and no aberrant cases were identified.[63]

Patient and public involvement

The research question and outcome measures were developed over a 3-year period during delivery of a work site back care education programme to a regional council in Queensland, Australia. This involved both formal and informal work-related discussions with attendees and management enabling the programme and exercise selection to be progressively modified. This procedure informed programme progression, specifically the exercises and their relation to the presence or not of LBP, and ensured the priorities of exercise simplicity for the identification and prevention of LBP. The experience gained by this process refined the programme and the selected preferences guiding the statistical relation between the exercises and the presence or not of LBP. The results of each session were disseminated immediately to each participant, and after the initial 3 years of the programme and pilot statistical analysis, the statistical relation was discussed with the council management as part of the programme feedback.

RESULTS

For descriptive purposes, a cross-tabulation of LBP (0=none, 1=some, 2=most) and the number of exercises accomplished is presented in table 3. Most participants reporting no LBP could complete most exercises. For individuals with no LBP, 85.5% could complete at least four exercises. Exercise completion dropped significantly for participants with 'some' LBP. In this group, only 22.9% were able to complete four or more exercises, and for participants with 'most' LBP, only 10.5% were able to complete four or more exercises. Analysing participants in each category who failed to complete more than one exercise, the pattern is reversed. Only 2.9% of those with no LBP had trouble completing more than one exercise, while 23.7% of those with 'some LBP' and 74.3% of those with 'most LBP' were unable to complete more than one. A Pearson χ^2 test was performed demonstrating a significant relationship between the variables of 'LBP' and 'number of exercises performed' ($X^2_{(10)}=300.61$, $p<0.001$).

A multinomial logistic regression predicting LBP (0, 1, 2, with 0 being the reference group) from the count of exercises that could be completed (EX_SUM, ranging from 0 to 5), showed a strong effect (initial-2LL=348.246, final-2LL=73.620, $X^2_{(2)}=274.626$, $p<0.001$; table 4).

As presented in table 5, as EX_SUM increased incrementally, the odds of reporting some LBP or most LBP reduced substantially: OR=0.34 (95% CI 0.27 to 0.44) and 0.17 (95% CI 0.12 to 0.23), for LBP=1 and 2, respectively. No curvilinear effect was present nor any gender effect.

A second multinomial logistic regression with the five exercise variables entered individually, rather than entering the total number accomplished, evaluated whether tests were individually predictive of LBP. As shown in table 6, overall, the effect was similarly strong[63] (initial-2LL=429.93, final-2LL=147.40, $X^2_{(2)}=282.53$, $p<0.001$).

As table 7 presents, most exercises were individually predictive of LBP (when LBP=1, EIL was not uniquely predictive with all other variables in the equation). All others were statistically significant ($p<0.002$) with ORs ranging in magnitude from 0.21 to 0.38. For 'Most' LBP (LBP=2), all exercises were significant independent predictors of LBP (all $p<0.017$), with ORs ranging from 0.09 to 0.35.

Sensitivity for the first analysis (per cent of participants with LBP correctly classified into LBP category) was 82.3%, and specificity (percent of participants with no LBP classified as such) was 85.6%. The positive predictive

Table 3 Exercises accomplished as a function of LBP

Number of exercises completed		LBP 0 None	1 Some	2 Most	Total
0	Count	1	8	33	42
	% within LBP	0.6	5.6	31.4	10.0
1	Count	4	26	45	75
	% within LBP	2.3	18.1	42.9	17.8
2	Count	5	32	12	49
	% within LBP	2.9	22.2	11.4	11.6
3	Count	15	45	4	64
	% within LBP	8.7	31.3	3.8	15.2
4	Count	58	20	6	84
	% within LBP	33.5	13.9	5.7	19.9
5	Count	90	13	5	108
	% within LBP	52.0	9.0	4.8	25.6
Total	Count	173	144	105	422
	% within LBP	100.0	100.0	100.0	100.0

LBP, low back pain.

value (true positives divided by true and false positives) was 89.1%, and negative predictive value (true negatives divided by true and false negatives) was 77.1%. Sensitivity for the second analysis was 79.5%, and specificity was 87.9%. Positive predictive value was 90.4%, and negative predictive value was 74.9%.

We also took into consideration a simple analysis relating the presence or absence of LBP to exercises. This approach, combining two groups of LBP (some and mostly) into one category potentially reduces the goodness of the analysis by combining two different groups into one heterogeneous group. If the two groups were distinct, this would increase error variance and decrease the power and informativeness of the analyses. Ancillary binary logistic regression analyses therefore tested the null hypothesis that the two LBP groups were similar. Results of this analysis, which predicted LBP (ie, some vs mostly) showed that EX_SUM was significantly related to this outcome (initial-2LL=339.05, final-2LL=284.96, $X^2_{(1)}$=54.09, p<0.001), leading us to reject the null hypothesis and assert that these two groups are significantly distinct.

DISCUSSION

Previous research demonstrated a relationship between dynamic physical tests, self-reported LBP and reduced function.[38] However, such research has been neglected in recent decades[29–32] as focus shifted towards physiological and radiological findings[9 10] and biopsychosocial attributes.[3 6 7 11] Grönblad *et al*[38] showed three physical exercises (repetitive sit-ups, squats and EIL) had a positive correlation with LBP. Our current study builds on this research as it expands the number of test exercises. It also shows a higher statistical correlation between physical exercise tests and LBP than found previously. These findings with robust effect sizes, and the 95% CIs,[63] demonstrate a substantial relationship. Our results indicate that for each increase in the exercise number accomplished, the odds of having some LBP were about one-third less than that of those participants accomplishing one fewer exercise. The authors feel these research findings are generalisable to settings other than those originally tested due to several factors. The council worker population included 21 distinct occupational categories across manual and sedentary requirements under sustained and moveable loads,[48 49] field work in both outdoor and

Table 4 Model summary entering only count of exercises completed (EX_SUM)

Model fitting information

Model	Model fitting criteria: −2 log likelihood	Likelihood ratio tests: χ^2	df	Sig.
Intercept only	348.246			
Final	73.620	274.626	2	0.000

Table 5 Parameter estimates

LBP*		B	SE	Wald	df	Sig.	Exp(B)	95% CI for Exp(B) Lower bound	Upper bound
1.0 some	Intercept	3.622	0.469	59.645	1	0.000			
	EX_SUM	–1.069	0.121	77.475	1	0.000	0.343	0.271	0.436
2.0 most	Intercept	4.628	0.497	86.653	1	0.000			
	EX_SUM	–1.784	0.158	127.031	1	0.000	0.168	0.123	0.229

*The reference category is: 0 none.
LBP, low back pain.

indoor settings and included a broad distribution of age groups and both genders that indicate the abilities and capacities of workers that present some of the highest potential risk of LBP.[50 51]

This study clearly showed that the presence of LBP is significantly statistically related to the ability to perform the chosen exercise tasks. All exercises were uniquely predictive of LBP (except EIL where LBP=1). The total number of exercises completed was strongly related to LBP. The relevance of a gender effect and potential curvilinear effects was tested as per the accepted recommendation[63] and found to have no effect on the results. Effectively, those able to perform more exercises were substantially less likely to report LBP. Consequently, these exercises have the potential to be a part of the areas of recommended necessary investigation in future research[3 11] in terms of the ability to provide a clinical diagnosis related to the potential or risk that an individual may develop LBP and perhaps even future impairment.

The ability to perform repeated squatting has been demonstrated to be inversely related to LBP as the balance between hip and lumbar spine mobility must be met, that is, better squatting ability is associated with reduced LBP.[47] These researchers found females more susceptible to LBP if they had lower physical performance capacity, a finding not evident in our study. Furthermore, excess/prolonged squatting has a negative effect through increased LBP.[64] Similarly, EIL is beneficial and facilitates lumbar lordosis maintenance.[65] There is a direct link between a reduced lordosis and LBP.[66] Lordosis maintenance is essential for disc symptomology centralisation for LBP management and preventative exercise strategies.[65 67] The exercise alone was not predictive of LBP.

Back endurance testing is a statistically accurate LBP screening test as poor performance in static back endurance correlates to higher incidence.[68 69] However, EIL is a passive test using the arms as the prime mover. It is possible that individuals with excessive lumbar extensor activation and substitution during this test may confound the results. Furthermore, some studies have indicated that trunk muscle strength measures in isolation are unrelated to LBP symptoms and functional ability.

Exercise therapy is an efficient, cost-effective LBP management strategy,[70 71] but there is no evidence to support any single exercise. Coordinated muscle activity around the lumbopelvic region is considered vital for mechanical spinal stability.[36 72] Several rehabilitative 'stabilisation exercise' approaches emphasise retraining functional movement patterns, rather than focusing on specific muscles.[35 73 74] The tests we chose activate and challenge the global muscles of the abdomen and trunk, the 'abdominal brace' mechanism[75] and their ability to act and interact in a synergistic and functional manner. We screened functional test performance where the aim was assessing participants' functional status regardless or not of LBP and its known or potential cause. As LBP increases in industrial societies with no clear cause, it is important to consider risk factors of physical workload and awkward posture[7] as well as preventative strategies that may play a key role in reducing healthcare system demands and societal support. The exercise tests we used primarily address abdominal and lumbopelvic muscles and their coordination with lower limb muscle activity and maintenance of balance. This coordination was recently defined as 'integral' in understanding lumbar stability as a complex integrated model.[36] Personal efficiency in physical self-test completion can act as a screening methodology for individuals at risk of LBP. It is, however, important that the method of test performance is considered, for example, there is no relation demonstrated between sit-up performance and LBP when the feet are held.[76] This action preferences hip flexor activity over abdominal participation.

Table 6 Model summary when five exercises entered individually

Model fitting information

Model	Model fitting criteria –2 log likelihood	Likelihood ratio tests χ^2	df	Sig.
Intercept only	429.927			
Final	147.397	282.530	10	0.000

Table 7 Parameter estimates when exercises entered individually

Parameter estimates									
								95% CI for Exp(B)	
LBP*		B	SE	Wald	df	Sig.	Exp(B)	Lower bound	Upper bound
1.0	Intercept	3.320	0.520	40.719	1	0.000			
	EX1_EIL	−0.148	0.401	0.136	1	0.713	0.863	0.393	1.894
	EX2_situp	−1.326	0.284	21.827	1	0.000	0.266	0.152	0.463
	EX3_legext	−1.101	0.362	9.246	1	0.002	0.332	0.164	0.676
	EX4_squat	−0.959	0.298	10.337	1	0.001	0.383	0.214	0.688
	EX5_riseup	−1.540	0.413	13.929	1	0.000	0.214	0.096	0.481
2.0	Intercept	4.415	0.539	67.084	1	0.000			
	EX1_EIL	−1.050	0.440	5.698	1	0.017	0.350	0.148	0.829
	EX2_situp	−2.010	0.429	21.977	1	0.000	0.134	0.058	0.310
	EX3_legext	−1.666	0.432	14.854	1	0.000	0.189	0.081	0.441
	EX4_squat	−1.532	0.414	13.672	1	0.000	0.216	0.096	0.487
	EX5_riseup	−2.392	0.456	27.495	1	0.000	0.091	0.037	0.224

*The reference category is: 0.
LBP, low back pain.

Alternative actions that preference abdominal muscles, for example, partial curl-up, are more highly correlated to LBP.[77 78] Our results provide guidance for future work that may contribute to a comprehensive screening, prevention and management approach to LBP.

Study strengths and limitations

The strengths of this study include the cross-sectional nature, the sample including both genders, diverse age groups and occupations but within one organisation and geographical region. This enabled continuity, and a degree of homogeneity in the otherwise varied sample, that strengthened the statistical findings with respect to general working populations. The sample had adequate power and representation of the constructs under consideration. The findings were statistically substantial in the effect size and the determined relationship between the physical tests and the presence of LBP. Causality, however, cannot be inferred from this study.

Other exercise tests may have similar utility. In choosing the exercise tests, we did not consider exercise dose and specificity for age and gender and these may be confounding factors. However, the statistical findings showed that the exercises chosen were relevant and that neither gender nor age influenced the results.

Other potential limitations were the use of a self-assessed diagnosis as participants were not physically examined and the reported LBP was their interpretation of the area ‘above the buttocks to the region of waist’. Additionally, that participant self-reported gender was the only potential moderator or confounding variable included in the data. As noted above, gender itself was not a significant predictor in any analysis (p>0.80) and thus not included in analyses reported. We were unable to test for a significant interaction between gender and exercises (eg, EX_SUM) due to quasicomplete separation in the data. However, a trend appeared where the effects for males were *slightly* stronger. This might represent a direction for future research within larger samples or simply a sample artefact.

Future research

Determining the exercises indicative of LBP is imperative for diagnosis and setting discharge goals; the next step is to determine which intervention regimen/s could improve the ability to harmoniously perform and maintain the exercises in an optimised and scalable manner. This would require a prospective, longitudinal study with symptomatic/non-symptomatic LBP patients. Challenges in assessing efficacy are test standardisation plus gender variation in repetitions number or degree of movement as males are generally stronger and females more flexible. Furthermore, all measurements at baseline and follow-up must be accurate and sensitive. Consequently, a combination of physical tests and patient-reported outcomes are needed, where many currently preferred tools may not be sufficiently sensitive.[27]

Furthermore, this study had limited demographic variables. Consequently, future research may consider moderating factors aside from gender. Perhaps age is a differential consideration. However, the very strong analyses effects observed and that our lack of explicitly modelling these hidden variables would have biased the results towards the null, it is unlikely that unobserved variables are true confounders but might clarify and increase the sensitivity of some effects if modelled. As an observational study, however, it was not possible to indicate whether gradually training individuals to complete these five exercises could facilitate reductions in LBP. From the authors’ clinical management protocol, it may be speculated that this appears possible.

Conclusion

In a group of 422 predominantly male, Australian Council workers presenting in a mixed general working population, the ability to complete or not-complete five simple functional exercises showed a significant and meaningful clinical correlation with the presence or absence of LBP. Those able to perform more exercises were significantly less likely to report the presence of LBP, either sometimes or most of the time. Conversely, those unable to perform any or one exercise were more likely to report the presence of LBP most of the time. These findings could be useful for diagnostic purposes, and we hypothesised that training pain-free individuals to be able to complete the five exercises on a regular basis could facilitate prevention of LBP in a general working population. Furthermore, that a graded introduction of these or similar exercises as part of a supervised rehabilitation programme, for individuals recovering from an episode of LBP, may facilitate overall recovery and reduce recurrence. A prospective trial to investigate this hypothesis is to be initiated.

Author affiliations
[1]Research Department, Coolum Physiotherapy, Coolum Beach, Queensland, Australia
[2]Department of Ergonomics, University of Social Welfare and Rehabilitation Sciences, Tehran, Iran
[3]Human Movement, Independent Private Researcher, Placencia Village, Belize
[4]Department of Mathematical Sciences, Clemson University, Clemson, South Carolina, USA
[5]Department of Public Health Science, Clemson University, Clemson, South Carolina, USA
[6]School of Allied Health Sciences, Griffith University, Gold Coast, Queensland, Australia
[7]Mater Research, Mater Medical Research Institute, Brisbane, Queensland, Australia
[8]School of Health Professions, Zurich University of Applied Sciences, Winterthur, Switzerland
[9]Curtin Medical School, Curtin University, Perth, Western Australia, Australia
[10]UWA Medical School, University of Western Australia, Perth, Western Australia, Australia

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References

1. Deyo RA, Weinstein JN. Low back pain. *N Engl J Med Overseas Ed* 2001;344:363–70.
2. Balagué F, Mannion AF, Pellisé F, *et al*. Non-specific low back pain. *Lancet* 2012;379:482–91.
3. Buchbinder R, van Tulder M, Öberg B, *et al*. Low back pain: a call for action. *Lancet* 2018;391:2384–8.
4. GBD 2016 Disease and Injury Incidence and Prevalence Collaborators. Global, regional, and national incidence, prevalence, and years lived with disability for 328 diseases and injuries for 195 countries, 1990-2016: a systematic analysis for the Global Burden of Disease Study 2016. *Lancet* 2017;390:1211–59.
5. Murray CJL, Vos T, Lozano R, *et al*. Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet* 2012;380:2197–223.
6. Hartvigsen J, Hancock MJ, Kongsted A, *et al*. What low back pain is and why we need to pay attention. *Lancet* 2018;391:2356–67.
7. Machado GC, Ferreira PH, Maher CG, *et al*. Transient physical and psychosocial activities increase the risk of nonpersistent and persistent low back pain: a case-crossover study with 12 months follow-up. *The Spine Journal* 2016;16:1445–52.
8. Deyo RA. Treatments for back pain: can we get past trivial effects? *Ann Intern Med* 2004;141:957–8.
9. Kohns DJ, Haig AJ, Uren B, *et al*. Clinical predictors of the medical interventions provided to patients with low back pain in the emergency department. *J Back Musculoskelet Rehabil* 2018;31:197-204.
10. Dubois J-D, Cantin V, Piché M, *et al*. Physiological and psychological predictors of short-term disability in workers with a history of low back pain: a longitudinal study. *PLoS One* 2016;11:e0165478.
11. Foster NE, Anema JR, Cherkin D, *et al*. Prevention and treatment of low back pain: evidence, challenges, and promising directions. *Lancet* 2018;391:2368–83.
12. Steffens D, Ferreira ML, Latimer J, *et al*. What triggers an episode of acute low back pain? A case-crossover study. *Arthritis Care Res* 2015;67:403–10.
13. Gabel CP, Burkett B, Melloh M. The shortened örebro musculoskeletal screening questionnaire: evaluation in a work-injured population. *Man Ther* 2013;18:378–85.
14. O'Sullivan P. Diagnosis and classification of chronic low back pain disorders: maladaptive movement and motor control impairments as underlying mechanism. *Man Ther* 2005;10:242–55.
15. Pind R. Testing a New 10-Item Scale (Pind's LBP Test) for prediction of sick leave lasting more than three days or more than two weeks after a general practitioner visit for acute low back pain. *Spine* 2014;39:E581–E586.
16. Verbunt JA, Seelen HA, Vlaeyen JW, *et al*. Disuse and deconditioning in chronic low back pain: concepts and hypotheses on contributing mechanisms. *Eur J Pain* 2003;7:9–21.
17. Johnsen LG, Hellum C, Nygaard OP, *et al*. Comparison of the SF6D, the EQ5D, and the oswestry disability index in patients with chronic low back pain and degenerative disc disease. *BMC Musculoskelet Disord* 2013;14:148.
18. Melloh M, Aebli N, Elfering A, *et al*. Development of a screening tool predicting the transition from acute to chronic low back pain for patients in a GP setting: protocol of a multinational prospective cohort study. *BMC Musculoskelet Disord* 2008;9:167.
19. Williams CM, Hancock MJ, Maher CG, *et al*. Predicting rapid recovery from acute low back pain based on the intensity, duration and history of pain: A validation study. *European Journal of Pain* 2014;18:1182–9.
20. Hancock MJ, Maher CM, Petocz P, *et al*. Risk factors for a recurrence of low back pain. *Spine J* 2015;15:2360–8.
21. E F Graves L, C Murphy R, Shepherd SO, *et al*. Evaluation of sit-stand workstations in an office setting: a randomised controlled trial. *BMC Public Health* 2015;15:1145.
22. de Cássia Pereira Fernandes R, Pataro SMS, de Carvalho RB, *et al*. The concurrence of musculoskeletal pain and associated

work-related factors: a cross sectional study. *BMC Public Health* 2016;16:628.
23. Maus T. Imaging the back pain patient. *Phys Med Rehabil Clin N Am* 2010;21:725–66.
24. de Schepper EIT, Koes BW, Veldhuizen EFH, *et al*. Prevalence of spinal pathology in patients presenting for lumbar MRI as referred from general practice. *Fam Pract* 2016;33:51–6.
25. Khan I, Hargunani R, Saifuddin A. The lumbar high-intensity zone: 20 years on. *Clin Radiol* 2014;69:551–8.
26. van Abbema R, Lakke SE, Reneman MF, *et al*. Factors associated with functional capacity test results in patients with non-specific chronic low back pain: a systematic review. *J Occup Rehabil* 2011;21:455–73.
27. Gabel CP, Cuesta-Vargas A, Qian M, *et al*. The Oswestry Disability Index, confirmatory factor analysis in a sample of 35,263 verifies a one-factor structure but practicality issues remain. *European Spine Journal* 2017;26:2007–13.
28. de Schepper EIT, Koes BW, Oei EHG, *et al*. The added prognostic value of MRI findings for recovery in patients with low back pain in primary care: a 1-year follow-up cohort study. *European Spine Journal* 2016;25:1234–41.
29. Melloh M, Elfering A, Käser A, *et al*. What is the best time point to identify patients at risk of developing persistent low back pain? *J Back Musculoskelet Rehabil* 2015;28:267–76.
30. Gabel CP, Osborne J, Burkett B, *et al*. Letters. TO THE EDITOR: Linton SJ, Nicholas M, MacDonald S. Development of a short form of the Örebro Musculoskeletal Pain Screening Questionnaire. Spine (Phila Pa 1976) 2011;36:1891-5. *Spine* 2015;40:E913.
31. Sterud T, Tynes T. Work-related psychosocial and mechanical risk factors for low back pain: a 3-year follow-up study of the general working population in Norway. *Occup Environ Med* 2013;70:296–302.
32. Robinson HS, Dagfinrud H. Reliability and screening ability of the StarT Back screening tool in patients with low back pain in physiotherapy practice, a cohort study. *BMC Musculoskelet Disord* 2017;18:232.
33. Beneciuk JM, Bishop MD, Fritz JM, *et al*. The STarT back screening tool and individual psychological measures: evaluation of prognostic capabilities for low back pain clinical outcomes in outpatient physical therapy settings. *Phys Ther* 2013;93:321–33.
34. Mitchell T, O'Sullivan PB, Burnett A, *et al*. Identification of modifiable personal factors that predict new-onset low back pain: a prospective study of female nursing students. *Clin J Pain* 2010;26:275–83.
35. Hoffman J, Gabel CP. The origins of Western mind–body exercise methods. *Physical Therapy Reviews* 2015;20:315–24.
36. Hoffman J, Gabel P. Expanding Panjabi's stability model to express movement: A theoretical model. *Med Hypotheses* 2013;80:692–7.
37. Micheo W, Baerga L, Miranda G. Basic principles regarding strength, flexibility, and stability exercises. *Pm R* 2012;4:805–11.
38. Grönblad M, Järvinen E, Hurri H, *et al*. Relationship of the Pain Disability Index (PDI) and the Oswestry Disability Questionnaire (ODQ) with three dynamic physical tests in a group of patients with chronic low-back and leg pain. *Clin J Pain* 1994;10:197–203.
39. Broonen J-P, Marty M, Legout V, *et al*. Is volition the missing link in the management of low back pain? *Joint Bone Spine* 2011;78:364–7.
40. Henchoz Y, Kai-Lik So A. Exercise and nonspecific low back pain: a literature review. *Joint Bone Spine* 2008;75:533–9.
41. Ng JK, Richardson CA, Kippers V, *et al*. Relationship between muscle fiber composition and functional capacity of back muscles in healthy subjects and patients with back pain. *J Orthop Sports Phys Ther* 1998;27:389–402.
42. Goubert D, Oosterwijck JV, Meeus M, *et al*. Structural changes of lumbar muscles in non-specific low back pain: a systematic review. *Pain Physician* 2016;19:E985–E1000.
43. Mannion AF, Taimela S, Müntener M, *et al*. Active therapy for chronic low back pain part 1. Effects on back muscle activation, fatigability, and strength. *Spine* 2001;26:897–908.
44. Melloh M, Elfering A, Käser A, *et al*. Depression impacts the course of recovery in patients with acute low-back pain. *Behav Med* 2013;39:80–9.
45. Elfering A, Mannion AF. Epidemiology and risk factors of spinal disorders. In: Boos N, Aebi M, eds. *Spinal disorders – fundamentals of diagnosis and treatment*. Berlin Heidelberg, New York: Springer, 2008:153–73.
46. Marich AV, Hwang C-T, Salsich GB, *et al*. Consistency of a lumbar movement pattern across functional activities in people with low back pain. *Clin Biomech* 2017;44:45–51.
47. Grönblad M, Hurri H, Kouri JP. Relationships between spinal mobility, physical performance tests, pain intensity and disability assessments in chronic low back pain patients. *Scand J Rehabil Med* 1997;29:17–24.
48. Riihimäki H, Tola S, Videman T, *et al*. Low-back pain and occupation. A cross-sectional questionnaire study of men in machine operating, dynamic physical work, and sedentary work. *Spine* 1989;14:204–9.
49. Lao J, Hansen A, Nitschke M, *et al*. Working smart: an exploration of council workers' experiences and perceptions of heat in adelaide, South Australia. *Saf Sci* 2016;82:228–35.
50. Trask C, Bath B, Johnson PW, *et al*. Risk factors for low back disorders in saskatchewan farmers: fieled-based exposure assessment to build a foundation for epidemiological studies. *JMIR Res Protoc* 2016;5:e111.
51. Coenen P, Kingma I, Boot CRL, *et al*. Cumulative mechanical low-back load at work is a determinant of low-back pain. *Occup Environ Med* 2014;71:332–7.
52. Panjabi MM. Clinical spinal instability and low back pain. *Journal of Electromyography and Kinesiology* 2003;13:371–9.
53. Johnson CD, Whitehead PN, Pletcher ER, *et al*. The relationship of core strength and activation and performance on three functional movement screens. *J Strength Cond Res* 2018;32:1166–73.
54. Zannotti CM, Bohannon RW, Tiberio D, *et al*. Kinematics of the double-leg-lowering test for abdominal muscle strength. *Journal of Orthopaedic & Sports Physical Therapy* 2002;32:432–6.
55. Sullivan MS, Shoaf LD, Riddle DL. The relationship of lumbar flexion to disability in patients with low back pain. *Phys Ther* 2000;80:240–50.
56. Carlsson H, Rasmussen-Barr E. Clinical screening tests for assessing movement control in non-specific low-back pain. A systematic review of intra- and inter-observer reliability studies. *Man Ther* 2013;18:103–10.
57. Kessler RC, Adler L, Ames M, *et al*. The world health organization adult ADHD self-report scale (ASRS): a short screening scale for use in the general population. *Psychol Med* 1999;35:245–56.
58. Albarracin D, Johnson BT, Zanna MP. *The handbook of attitudes*. Hillsdale, NJ: Erlbaum, 2005.
59. Gabel CP, Michener LA, Melloh M, *et al*. Modification of the upper limb functional index to a three-point response improves clinimetric properties. *Journal of Hand Therapy* 2010;23:41–52.
60. Krosnick JA. *The handbook of questionnaire design*. New York: Oxford University Press, 1991.
61. Jacoby J, Matell MS. Three-point likert scales are good enough. *J Marketng Res* 1971;8:495–500.
62. Newcombe RG. Estimating the difference between differences: measurement of additive scale interaction for proportions. *Stat Med* 2001;20:2885–93.
63. Osborne JW. *Regression and linear modeling: Best practices and modern methods*. Thousand Oaks, CA: SAGE Publishing, 2017.
64. Cho NH, Jung YO, Lim SH, *et al*. The prevalence and risk factors of low back pain in rural community residents of Korea. *Spine* 2012;37:2001–10.
65. Halliday MH, Ferreira PH, Hancock MJ, *et al*. A randomised controlled trial protocol comparing McKenzie Therapy and motor control exercises on trunk muscle recruitment in people with chronic low back pain and directional. *Physiotherapy* 2015;101:232–8.
66. Chun SW, Lim CY, Kim K, *et al*. The relationships between low back pain and lumbar lordosis: a systematic review and meta-analysis. *Spine J* 2017;17:1180–91.
67. May S, Aina A. Centralization and directional preference: A systematic review. *Man Ther* 2012;17:497–506.
68. Bauer CM, Rast FM, Ernst MJ, *et al*. The effect of muscle fatigue and low back pain on lumbar movement variability and complexity. *Journal of Electromyography and Kinesiology* 2017;33:94–102.
69. Andersen K, Baardsen R, Dalen I, *et al*. Impact of exercise programs among helicopter pilots with transient LBP. *BMC Musculoskelet Disord* 2017;18:269.
70. van Middelkoop M, Rubinstein SM, Verhagen AP, *et al*. Exercise therapy for chronic nonspecific low-back pain. *Best Pract Res Clin Rheumatol* 2010;24:193–204.
71. Lin C-WC, Haas M, Maher CG, *et al*. Cost-effectiveness of guideline-endorsed treatments for low back pain: a systematic review. *European Spine Journal* 2011;20:1024–38.
72. McGill SM, Grenier S, Kavcic N, *et al*. Coordination of muscle activity to assure stability of the lumbar spine. *J Electromyogr Kinesiol* 2003;13:353–9.
73. Ikeda DM, McGill SM. Can altering motions, postures, and loads provide immediate low back pain relief: a study of 4 cases investigating spine load, posture, and stability. *Spine* 2012;37:E1469–75.

74. Bell JA, Burnett A. Exercise for the primary, secondary and tertiary prevention of low back pain in the workplace: a systematic review. *J Occup Rehabil* 2009;19:8–24.
75. Myrtos CD. Low Back Disorders. Evidence-Based Prevention and Rehabilitation. *J Canad Chiro Assoc* 2012;56:76.
76. Jackson AW, Morrow JR, Brill PA, *et al*. Relations of sit-up and sit-and-reach tests to low back pain in Adults. *J Orthop Sports Phys Ther* 1998;27:22–6.
77. Parfrey KC, Docherty D, Workman RC, *et al*. The effects of different sit- and curl-up positions on activation of abdominal and hip flexor musculature. *Appl Physiol Nutr Metab* 2008;33:888–95.
78. Moya-Ramón M, Juan-Recio C, Lopez-Plaza D, *et al*. Dynamic trunk muscle endurance profile in adolescents aged 14-18: Normative values for age and gender differences. *J Back Musculoskelet Rehabil* 2018;31:155-162.
79. Panjabi MM, Oxland TR, Yamamoto I, *et al*. Mechanical behavior of the human lumbar and lumbosacral spine as shown by three-dimensional load-displacement curves. *The Journal of Bone & Joint Surgery* 1994;76:413–24.
80. Steele J, Bruce-Low S, Smith D, *et al*. A randomized controlled trial of limited range of motion lumbar extension exercise in chronic low back pain. *Spine* 2013;38:1245–52.
81. Mazzone B, Wood R, Gombatto S. Spine kinematics during prone extension in people with and without low back pain and among classification-specific low back pain subgroups. *J Orthop Sports Phys Ther* 2016;46:571–9.
82. Apeldoorn AT, van Helvoirt H, Meihuizen H, *et al*. The Influence of Centralization and Directional Preference on Spinal Control in Patients With Nonspecific Low Back Pain. *J Orthop Sports Phys Ther* 2016;46:258–69.
83. McKenzie R, May S. *The lumbar spine: mechanical diagnosis and therapy, Volume 1*. New Zealand: Waikanae, New Zealand Spinal Publications, 2003.
84. Scannell JP, McGill SM. Disc prolapse: evidence of reversal with repeated extension. *Spine* 2009;34:344–50.
85. Youdas JW, Suman VJ, Garrett TR. Reliability of measurements of lumbar spine sagittal mobility obtained with the flexible curve. *Journal of Orthopaedic & Sports Physical Therapy* 1995;21:13–20.
86. Lehman GJ, Story S, Mabee R. Influence of static lumbar flexion on the trunk muscles' response to sudden arm movements. *Chiropr Osteopat* 2005;13:23.
87. Abboud J, Lardon A, Boivin F, *et al*. Effects of muscle fatigue, creep, and musculoskeletal pain on neuromuscular responses to unexpected perturbation of the trunk: a systematic review. *Front Hum Neurosci* 2017;10:667.
88. Fry DK, Huang M, Rodda BJ. Core muscle strength and endurance measures in ambulatory persons with multiple sclerosis. *Int J Rehabil Res* 2015;38:206–12.
89. Arokoski JP, Valta T, Kankaanpää M, *et al*. Activation of lumbar paraspinal and abdominal muscles during therapeutic exercises in chronic low back pain patients. *Arch Phys Med Rehabil* 2004;85:823–32.
90. Shields RK, Heiss DG. An electromyographic comparison of abdominal muscle synergies during curl and double straight leg lowering exercises with control of the pelvic position. *Spine* 1997;22:1873–9.
91. Byström MG, Rasmussen-Barr E, Grooten WJA. Motor control exercises reduces pain and disability in chronic and recurrent low back pain. *Spine* 2013;38:E350–E358.
92. Enoch F, Kjaer P, Elkjaer A, *et al*. Inter-examiner reproducibility of tests for lumbar motor control. *BMC Musculoskelet Disord* 2011;12:114.
93. Linek P, Saulicz E, Wolny T, *et al*. Intra-rater reliability of b-mode ultrasound imaging of the abdominal muscles in healthy adolescents during the active straight leg raise test. *Pm R* 2015;7:53–9.
94. Schoenfeld BJ. Squatting kinematics and kinetics and their application to exercise performance. *J Strength Cond Res* 2010;24:3497–506.
95. Clark DR, Lambert MI, Hunter AM. Muscle activation in the loaded free barbell squat. *J Strength Cond Res* 2012;26:1169–78.
96. Hsiang SM, Brogmus GE, Courtney TK, *et al*. Low back pain (LBP) and lifting technique — A review. *Int J Ind Ergon* 1997;19:59–74.
97. Welch N, Moran K, Antony J, *et al*. The effects of a free-weight-based resistance training intervention on pain, squat biomechanics and MRI-defined lumbar fat infiltration and functional cross-sectional area in those with chronic low back. *BMJ Open Sport Exerc Med* 2015;1:e000050.
98. Edwards S, Liberatore M. Reliability of a squat movement competency screen in individuals with a previous knee injury. *J Sport Rehabil* 2018;5:1–26.
99. Moran RW, Schneiders AG, Major KM, *et al*. How reliable are Functional Movement Screening scores? A systematic review of rater reliability. *Br J Sports Med* 2016;50:527–36.
100. Bonazza NA, Smuin D, Onks CA, *et al*. Reliability, validity, and injury predictive value of the functional movement screen: a systematic review and meta-analysis. *Am J Sports Med* 2017;45:725–32.
101. Bazrgari B, Shirazi-Adl A, Arjmand N. Analysis of squat and stoop dynamic liftings: muscle forces and internal spinal loads. *European Spine Journal* 2007;16:687–99.
102. Rahmani A, Viale F, Dalleau G, *et al*. Force/velocity and power/velocity relationships in squat exercise. *Eur J Appl Physiol* 2001;84:227–32.