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PREVENTION AND REHABILITATION: ORIGINAL RESEARCH

Predictors of functional improvement in people with chronic low back pain following a graded Pilates-based exercise programme

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A R T I C L E I N F O

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A B S T R A C T

Background: Several studies have investigated subgroups of patients with low back pain (LBP) most likely to benefit from Pilates or movement control exercises, but none have determined prognostic factors specifically for chronic LBP. This prospective cohort study aimed to determine predictors of change in disability in people with chronic LBP following a Pilates-based exercise programme and reports summarised integrated prediction statistics to aid clinical utility for determination of subgroups likely to benefit or not benefit from treatment.
Methods: Healthy adults ($n = 55$) with non-specific chronic LBP undertook a graded 6-week programme involving two 1-hour Pilates sessions/week (1 mat and 1 equipment-based) led in small groups by a trained Pilates instructor. Predictors of change in Patient-Specific Functional Scale (PSFS) were identified through regression analysis and used to develop clinical prediction statistics.
Results: Clinically important improvement ($n = 14$ of 48 analysed) was predicted by four variables: gradual rather than sudden onset of LBP, PSFS <3.7 points, absence of aberrant motions on forward bending, and body mass index >24.5 kg/m^2. Presence of ≥ 3 improved probability of success from 29% to 73%. Failure to improve ($n = 18$) was predicted by three variables: sudden onset of low back pain, patient-specific functional score ≥ 3.7, and difference between left and right active straight leg raise >7°. Presence of all three increased probability of failure from 38% to 80%.
Conclusions: A combination of five, easily measured variables were able to predict disability outcome following a graded programme of Pilates-based exercises in people with chronic LBP. Two common movement deficits were inversely related to positive changes in function which may call into question the structural mechanism of improvements observed.
Trial Registration: Australian New Zealand Clinical Trials Registry: ACTRN12616001588482

1. Introduction

Low back pain (LBP) affects at least 80% of people at some point in their lifetime, and up to two-thirds of the population in a 1-year period (McBeth and Jones, 2007; Patrick et al., 2014). The economic cost is substantial; per capita estimates of annual direct and indirect costs range between USD $370 to $500, for most studies undertaken in the United States, United Kingdom, Australia and Europe (Dagenais et al., 2008). In around 85% of cases, LBP cannot be directly attributed to a specific pathology, being classed as non-specific (Weiner and Nordin, 2010). LBP is often associated with disability, the expressed combination of physical impairment, distress, and illness behaviours (Bogduk, 2006). While most people show rapid improvement in pain and associated disability within the first month of experiencing LBP, recurrence is common (Pengel et al., 2003). Furthermore, approximately one-third report persistent pain, and around 20% substantial activity limitations one year after an acute LBP episode (Patrick et al., 2014).

The efficacy of management approaches including pharmaceutical, educative, psychological, passive (manual therapy), active (exercise), and combined approaches have been previously reviewed (e.g. Parthan et al., 2006; Weiner and Nordin, 2010). There is conflicting evidence for exercise therapy in favour of other non-pharmacological approaches (van Tulder et al., 2000), and the

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ability to determine and address specific deficits in movement control may be a key factor in success.

Motor control impairments have been identified in people with chronic and recurrent LBP, including changes in trunk muscle activation patterns (Hubley-Kozey and Vezina, 2002; Dankaerts et al., 2009), and reorganisation of the motor cortex (Tsao et al., 2008). Mannion et al. (2001) have shown that whilst the strongest predictors of LBP-associated disability include pain intensity and psychosocial factors (distress and fear-avoidance beliefs), movement-related variables (aberrant back muscle activation and impaired spinal range of motion) also show positive cross-sectional association with disability.

Corresponding with chronic LBP-associated motor control impairments, exercise emphasising movement control is among the more promising of therapies that have been investigated for chronic LBP (Bogduk, 2004; van Tulder et al., 2006). Exercise training appears to induce beneficial changes in the motor cortex (Adkins et al., 2006), and in the recruitment patterns of trunk muscles (Stevens et al., 2007; Tsao and Hodges, 2008). Pilates exercise, which focuses on dynamic control of trunk musculature, improves a range of physical fitness, functional and well-being measures (Bullo et al., 2015). More recent systematic reviews also support the efficacy of exercise therapy for improvement of pain and disability in chronic LBP, particularly when specific spinal stabilisation exercises are included and when comparison is with minimal interventions such as brief consultation or education (Hayden et al., 2005; Patti et al., 2015; Aladro-Gonzalvo et al., 2013; Haladay et al., 2013; Wells et al., 2014). Nonetheless, conclusions may be limited by insufficient numbers of quality trials (Aladro-Gonzalvo et al., 2013; Haladay et al., 2013; Wells et al., 2014), heterogeneity with respect to characteristics of the study populations, and also by the nature of interventions and outcome measures (Wells et al., 2014).

Tailoring treatment according to subgroup classification is a commonly recommended and applied clinical practice for nonspecific LBP, though the nature of suggested subgroups varies widely (Delitto, 2005; O'Sullivan, 2005; Kent and Keating, 2005). In a meta-analysis, Fersum et al. (2010) demonstrated a short-term benefit for disability, and short- and long-term benefits of 8–10 on 100 mm visual analogue scale for pain when applying subgroup classification with matched interventions for non-specific, chronic LBP. Notwithstanding, Fersum et al. identified only five studies that applied subgroup-based differentiated interventions. Evidence surrounding appropriate subgroups for chronic LBP is further hampered by a lack of randomised controlled trials that report responder analyses for interventions, namely analysis of the proportion and characteristics of participants who achieve pre-defined levels of improvement (Henschke et al., 2014).

Variables that have the strongest independent association with clinical outcomes can be identified using exploratory regression models. To aid clinical interpretability of their effect, predictions rules can be developed from sets of these variables. A resulting clinical prediction rule (CPR), indicates the observed probability of occurrence of an outcome of interest, normally predefined clinical success or failure (Laupacis et al., 1997). The purpose of this exploratory study was to identify variables that predict clinically meaningful changes in disability rating in people with chronic non-specific LBP following a graded Pilates-based exercise programme, which emphasised movement control. In addition, CPRs to identify subgroups of patients likely to benefit, or not benefit, from such an exercise programme were developed by determining a subset of predictor variables which maximise specificity and sensitivity of a successful or unsuccessful outcome.

2. Methods

2.1. Study sample

Participants aged 25–65 years with current LBP of either ≥6 months duration or with recurrent episodes in the last year were recruited via community notices to a prospective cohort study from April–July, 2009. Exclusion criteria were known or suspected pregnancy; osteoporosis; signs of spinal pathology (e.g. tumour, infection, fracture); signs of nerve root compression; history of spinal or abdominal surgery within the previous year; any contra-indications to exercise; or any previous regular involvement in Pilates or back-exercise classes. A target sample size of 41 was calculated using G*Power (Faul et al., 2007). based on detection of an effect size of 0.4. Planned over-recruitment (30%) allowed for drop-out. All participants were informed of the study procedures and gave written informed consent. The study was approved by the institutional research ethics committee (UREC 2009–923) and is registered as a clinical trial (ACTRN12616001588482).

2.2. Pre-intervention assessments

One week before the intervention, LBP-related disability was measured using the Patient-Specific Functional Scale (PSFS) (Stratford et al., 1995). The PSFS is a reliable (ICC = 0.97) (Stratford et al., 1995) and well validated (Abbott and Schmitt, 2014) outcome measure for which 3–5 patient-nominated activities of importance are scored from 0–10 (unable–able to perform activity at pre-injury level).

Participants then completed questionnaires and underwent a physical assessment. Measures included demographic and anthropomorphic variables; characteristics of pain; activity interference, beliefs, and reported behaviours; other psychosocial factors; musculoskeletal examination findings; flexibility measures; movement control tests; and trunk muscle endurance tests (see Supplementary File 1 for a full list of variables and associated citations).

2.3. Outcome assessment

The PSFS was readministered one week after completion of the intervention. An improvement of 4.3 points on the average score has been found to equate to a 'large' change on the global rating of change scale (a measure of the patient's perception of change) (Stratford et al., 1995). and an improvement of ≥4 points was therefore used as an indicator of clinically important improvement (classified as 'success'). A change of 0.8 points correlates with a small change on the global rating of change scale (Stratford et al., 1995). As a small change was not considered clinically meaningful, patients with improvement of ≤1 point were classed as failing to respond (classified as 'failure'). The term 'improvement' is used to identify participants whose PSFS score increased between 1 and 4 points.

2.4. Intervention

The programme, set in a metropolitan Pilates clinic in Auckland, New Zealand, consisted of 12 exercise classes of 1-hour duration, scheduled over a period of 6 weeks. Every participant attended one mat class and one reformer (Fig. 1) class per week. The mat class was performed while lying supine or side-lying on the ground, or in a 4-point kneeling position, and sometimes included props to support or to challenge the participant during exercises. The reformer is a spring-loaded carriage on which the participant lies, sits or stands, and was used to provide either external resistance or

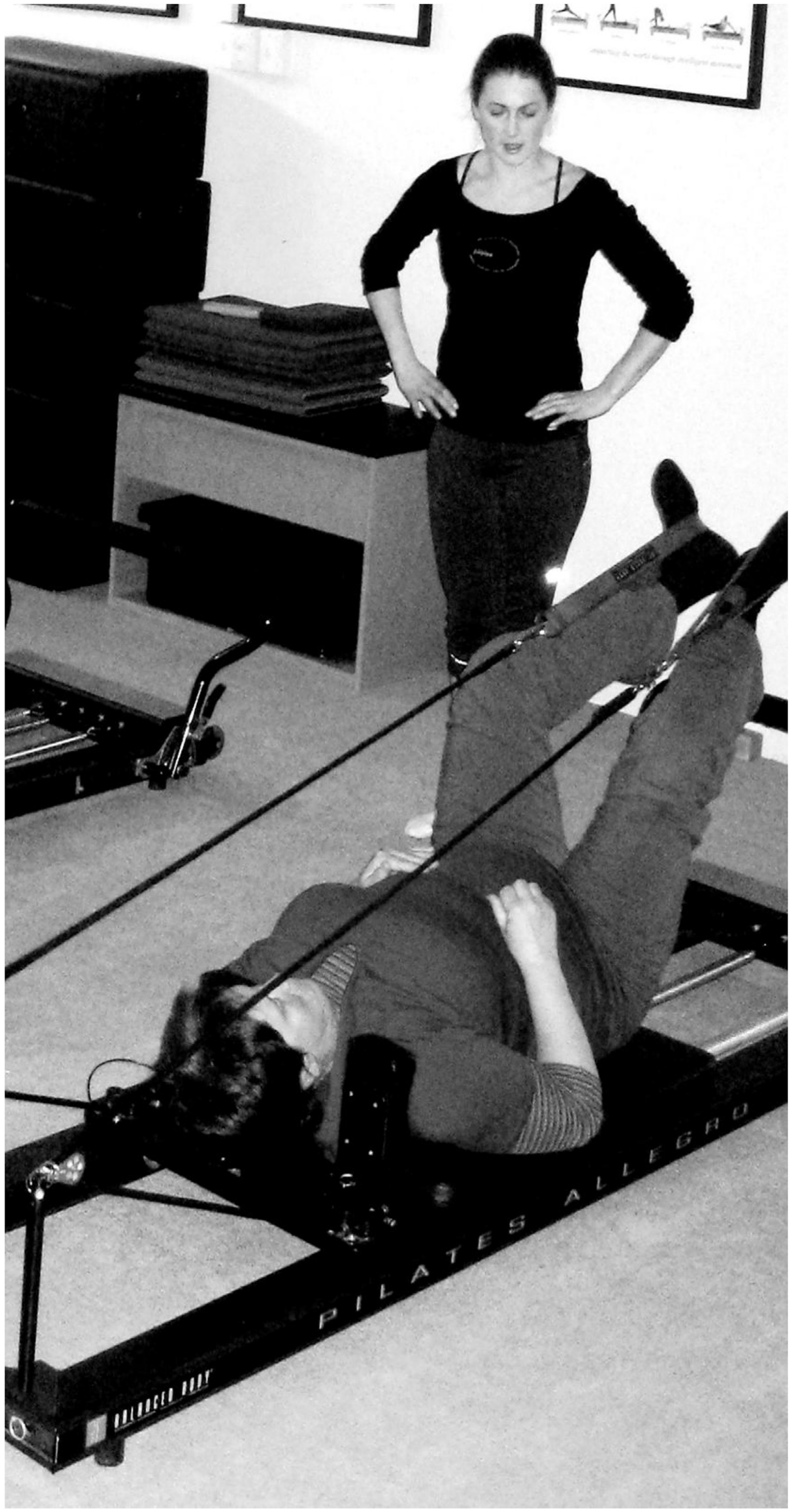

Fig. 1. Pilates recliner.

assistance. All classes were supervised by a trained exercise practitioner (Pilates instructor with 5 years' experience) and conducted in groups of maximum 7 participants for the reformer classes and maximum 16 participants for the mat classes. The exercise practitioner was not involved in administering the questionnaires and was blinded to the scores of predictor and outcome measures. Additional sessions were provided for participants who missed scheduled classes, ensuring a 100% attendance rate for all participants.

The exercises were progressively graded and were designed to improve body awareness and movement control. Exercise progressed from awareness of breathing and contraction of pelvic floor and abdominal muscles, through to maintaining control of spinal movement whilst performing dynamic tasks that involved leg and arm motion. Other exercises encouraged spinal mobility and stretching of the hip and leg muscles. Exercises could be made more challenging by removing one point of ground support or by increasing the length of the lever, by extending an arm or leg away from the body central axis. More challenging exercises that incorporated control of the spine in seated and standing positions were also practiced on the reformer in the latter stages of the intervention (see Supplementary File 2 for a detailed description of the Pilates intervention).

2.5. Data analysis

Potential predictor variables were grouped into related categories in order to assess Pearson's correlations with the outcome variables ('success', 'failure' or PSFS change) and with each other. To minimise the chance of excluding potentially important predictors, variables with significance levels of $P < 0.10$ when correlated with any one of the three outcome measures were included in the follow-up regression models. To limit covariance, when two potential predictors from the same category were correlated ($r > 0.30$, $P < 0.05$), only the variable more highly correlating with the outcome variables was included in the models.

A stepwise multiple linear regression model was applied to identify determinants of change in PSFS score and two logistic regression models to determine predictors that increased the probability of 'success' and 'failure'. Backward entry procedures were used for the initial regression models ($P_{out}<0.05$, $P_{in} = 0.05$), as they are less prone than forward models to suppressor effects (Field, 2009).

The continuous predictor variables identified through logistic regression analysis were plotted on receiver operating characteristic (ROC) curves. To dichotomise predictor variables and simplify resulting CPRs, cut-points were determined by consensus between two investigators for the point on each ROC curve closest to the upper left hand corner, representing the highest accuracy of positive/negative prediction. Logistic regression models for 'success' and 'failure' were applied to the appropriate dichotomised variables to eliminate any variables that were unstable, and to calculate Hosmer-Lemeshow R^2 values that estimate the model fit. Chi-squared tests were run for each of the outcome variables ('success' and 'failure') with different combinations of their predictors. Sensitivity and specificity values were calculated and, when necessary, a value of 1 (i.e. 1 person) was added to all cells used to calculate these figures to avoid division by zero. Combinations with the highest likelihood ratios were used for the clinical prediction rules for 'success' and 'failure'. All statistical analysis was conducted using SPSS (IBM SPSS, Armonk, NY. IBM Corp.)

3. Results

Of 67 participants who were interviewed, 55 were eligible and able to commit to the class times. Five people failed to complete the study due to work commitments ($n = 2$), family illness ($n = 1$) and because the classes aggravated their pain ($n = 2$). A further two data sets were unusable because participants had significantly altered some questions. Therefore, data from 48 people, 32 (67%) female, were included in the analyses. Their baseline characteristics are outlined in Table 1. The average PSFS score was 3.5 ± 1.3 (mean ± SD) at baseline, and improved to 6.3 ± 2.0 following the intervention ($p < 0.001$). Based on change in PSFS score there were 14 'success' cases, 16 'improvement' cases, and 18 'failure' cases classified.

Eleven predictor variables were retained after correlational analysis with PSFS (Table 1). Two of these, history of traumatic onset of LBP and average lateral trunk muscle endurance time were removed due to high correlation with another predictor: gradual/sudden mode of onset of LBP ($r = -0.48$, $P < 0.001$) and spinal extensor muscle endurance time ($r = 0.38$, $P < 0.01$) respectively.

3.1. Regression models

The nine remaining potential predictors were entered into the

Table 1
Participant characteristics at baseline and their correlation with change in Patient-Specific Functional Scale for low back pain-related disability.

Variable	All subjects ($n = 48$)	Success[b] with treatment ($n = 14$)	Improvement[c] with treatment ($n = 16$)	Failure[d] with treatment ($n = 18$)	r	P value
Age (y)	41 ± 11	45 ± 11	42 ± 12	38 ± 8	0.27	0.07
BMI (kg/m^2)	26.4 ± 4.7	28.2 ± 5.7	24.9 ± 4.5	26.3 ± 3.8	0.25	0.09
Mode of onset (% gradual)	35%	64%	31%	17%	0.38	0.01
[a]Traumatic onset (% yes)	29%	7%	31%	44%	−0.31	0.03
Fear-avoidance beliefs about work	14 ± 12	16 ± 11	18 ± 14	10 ± 8	0.31	0.03
PSFS functional score	3.5 ± 1.3	2.9 ± 0.9	3.3 ± 1.3	4.3 ± 1.2	0.47	<0.01
Increased segmental mobility (% present)	40%	21%	44%	50%	−0.36	0.01
Aberrant motions on forward bending (% present)	42%	21%	62%	39%	−0.26	0.07
Active SLR difference (deg.)	5 ± 5	4 ± 4	3 ± 3	7 ± 7	−0.27	0.06
Spinal extensor muscle endurance time (s)	126 ± 61	108 ± 59	125 ± 67	141 ± 56	−0.31	0.03
[a]Lateral trunk muscle endurance time (s)	49 ± 34	38 ± 26	45 ± 34	61 ± 39	−0.25	0.08

BMI = body mass index; PSFS = Patient-Specific Functional Scale; SLR = straight leg raise.
Note: Values are mean ± SD unless otherwise stated.
[a] Variables not entered into the regression models due to correlation with another potential predictor.
[b] Success = improvement in PSFS score by ≥ 4 points.
[c] Improvement = improvement in PSFS score by 2–3 points.
[d] Failure = improvement in PSFS score by ≤ 1 point.

Table 2
Predictors retained in the multiple linear regression model for PSFS change.

Variable	*B*	*SE B*	*β*
PSFS functional score	−0.64**	0.20	−0.37
Gradual vs sudden onset of LBP	1.51**	0.53	0.33
Aberrant motions on forward bending	−1.14*	0.52	−0.25
Age	0.07**	0.02	0.33
Spinal extensor muscle endurance time	−0.01*	0.00	−0.29
(Constant)	3.42*	1.32	–

Note: Model $R^2 = 0.52$, * $P < 0.05$, ** $P < 0.01$.
B = unstandardised beta co-efficient, SE = standard error, β = standardised beta co-efficient.
PSFS = Patient-Specific Functional Scale; LBP = low back pain.

multiple linear regression model, and into logistic regression models for ‘success’ and ‘failure’. Five variables were also retained in the multiple linear regression model: age (positive); gradual mode of onset of LBP (positive); PSFS score (negative); presence of aberrant motions on forward bending (negative); and spinal extensor muscle endurance time (negative) (Table 2). These five variables cumulatively explained 52% of variance in PSFS change ($P < 0.001$).

Variables retained in the success model were age (positive predictor); body mass index (positive); gradual mode of onset of LBP (positive); PSFS score (negative); and presence of aberrant motions on forward bending (negative). Cumulatively, these explained 45% of variance in the probability of ‘success’ ($P < 0.001$). Variables retained in the failure model were age (negative); gradual mode of onset of LBP (negative); PSFS score (positive); left/right active straight leg raise difference (positive); and spinal extensor muscle endurance time (positive), cumulatively explaining 44% of variance in the probability of ‘failure’ ($P < 0.001$).

3.2. Clinical prediction rules

After dichotomising the variables, age (cut-off = 40 y) was no longer a predictor of ‘success’ or ‘failure’, and spinal extensor muscle endurance time (cut-off = 75 s) was not a predictor of ‘failure’ in the repeated logistic regression models. The predictors of ‘success’ were PSFS score <3.7 points; body mass index >24.5 kg/m^2; gradual onset of LBP; and absence of aberrant motions on forward bending; while the predictors of ‘failure’ were PSFS score ≥3.7; active SLR difference ≥7°; and sudden onset of LBP (Table 3). The remaining four variables for ‘success’ explained 48% of the variance in outcome ($P < 0.001$), while the three ‘failure’ variables explained 40% of the variance in outcome ($P < 0.001$).

Using the dichotomised variables, two clinical prediction rules were constructed, one to predict ‘success’, and one to predict ‘failure’. Accuracy statistics, likelihood ratios and probability of outcome were calculated for each rule (Tables 4 and 5). The probability of ‘success’ for the entire sample was 29%. When at least three of the four success predictors were present, the probability of ‘success’ increased to 73%, and when participants were positive for all four predictors, their probability of ‘success’ was 82%. The probability of ‘failure’ for the entire sample was 38%, but when all three failure predictors were present, the probability of ‘failure’ increased to 80%.

4. Discussion

Prescriptive clinical prediction rules have received much attention in recent LBP literature and they are now emerging for common treatment modalities for acute LBP (May and Rosedale, 2009). Stolze et al. (2012) derived a CPR for recovery from current LBP, of both acute and chronic duration, following a Pilates-based exercise programme. One of five independent predictors of a successful pain outcome was pain duration ≤6 months, which applied to 28% of participants (Stolze et al., 2012). Here, we report predictors of a patient-centred disability outcome in patients only with chronic or recurrent LBP, in whom exercise-based rehabilitation has demonstrated efficacy (van Tulder et al., 2000; Kucukcakir et al., 2013; Patti et al., 2015).

Table 3
Dichotomised predictors retained in the logistic regression models.

Predictors	*B*	*SE B*	Exp *B* (95% CI)
a) Success model (Hosmer-Lemeshow $R^2 = .48$)			
PSFS functional score <3.7	3.95**	1.40	51.91 (3.33–808.95)
Gradual onset of LBP	2.98*	1.23	19.69 (1.75–221.32)
BMI >24.5	3.09**	1.33	22.03 (1.64–295.66)
No aberrant motions on forward bending	2.02†	1.05	7.52 (0.97–58.61)
(Constant)	−8.15**	2.44	–
b) Failure model (Hosmer-Lemeshow $R^2 = .40$)			
PSFS functional score > 3.7	2.54**	0.83	12.71 (2.49–64.73)
Sudden onset of LBP	1.79†	0.91	5.98 (1.00–35.80)
Active SLR difference > 7°	1.73*	0.88	5.65 (1.01–31.54)
(Constant)	−3.59**	1.09	–

Note: $^{\dagger}P < 0.06$, $^{*}P < 0.05$, ** $P < 0.01$.
B = beta co-efficient; SE = standard error; Exp B = exponential beta co-efficient.
PSFS = Patient-Specific Functional Scale; LBP = low back pain; BMI = body mass index; SLR = straight leg raise.

Table 4
Clinical prediction rule for success.

Combination of Variables	Sensitivity	Specificity	Positive LR	Probability of success
Variables: Gradual onset of LBP, no aberrant motions on forward bending, PSFS functional score <3.7, BMI >24.5				
All 4 variables present	0.31*	0.97*	11.25*	82%
At least 3	0.79	0.88	6.68	73%
At least 2	1.00	0.35	1.55	39%
At least 1	1.00	0.06	1.06	30%

Note: Probability of success for all participants was 29% *value of 1 added to all cells used to calculate this value to avoid division by zero error.
LR = likelihood ratio; LBP = low back pain; PSFS = Patient-Specific Functional Score; BMI = body mass index.

Table 5
Clinical prediction rule for failure.

Combination of variables	Sensitivity	Specificity	Positive LR	Probability of Failure
Variables: Sudden onset of LBP, PSFS functional score >3.7, Active SLR difference >7°				
All 3 variables	0.22	0.97	6.67	80%
At least 2	0.83	0.80	4.17	72%
At least 1	1.00	0.30	1.43	46%

Note: Probability of failure for all participants was 38%.
PSFS = Patient-Specific Functional Scale; Active SLR difference = difference between left and right active straight leg raise.

In the current study, people with chronic LBP who met all criteria of either one of the two CPRs increased their chances of 'success' or 'failure' from less than 40% to greater than 80% following a 6-week Pilates-based exercise programme. This is comparable to the increase in probability of success from 54% to 93% for the CPR derived by Stolze et al. for acute and chronic LBP (Stolze et al., 2012), and superior to the increase in probability of success of stabilisation exercises for LBP (33%–67%) noted for a CPR developed by Hicks et al. (2005). The lower explanatory power of the model here, multiple regression R^2 of 0.52, compared to $R^2 = 0.67$ reported by Flynn et al. (2002) for variables predicting success of spinal manipulation on LBP, is likely to relate to the poorer overall prognosis for chronic patients with greater symptom duration (Flynn et al., 2002; Stolze et al., 2012), which brings with it potential interplay of other predictive factors.

The five variables that were able to predict outcome for chronic LBP here reflect functional, mobility, and body composition, are all easily and quickly assessed in a clinical setting, and are typically included in routine physical examination.

4.1. Predictors of clinical success and failure

The single strongest predictor of outcome was the pre-intervention PSFS score. A low score, meaning high levels of disability, predicted 'success', while a higher score, identifying lower levels of disability, predicted 'failure'. Higher level of disability when seeking care is generally seen as a predictor of poor prognosis for resolution of chronic LBP patients (Menezes Costa et al., 2009), though initial limitations in activities of daily living have previously been associated with greater improvements, of unspecified magnitude, following functional restoration (Bendix et al., 1998).

Mode of LBP onset was another consistent predictor of outcome. Gradual onset predicted 'success', while sudden onset predicted 'failure.' In acute LBP patients, a history of sudden, not gradual, onset of LBP favours rapid recovery with general practitioner care (MacFarlane et al., 1999), however the role of mode of onset LBP outcomes remains unclear.

In this study, the absence of aberrant motion during forward bending was found to be a predictor of clinically important improvement in disability, and a moderate or greater difference between the right and left leg active straight leg raise was a predictor of 'failure'. Both tests are hypothesised to measure ability in maintenance of lumbopelvic control and motor control changes may result from adaptive or maladaptive responses to pain (O'Sullivan, 2005). Here, following an intervention designed to improve movement control, normal lumbopelvic control predicted success whilst asymmetrical straight leg raise predicted failure. It is possible that participants either required some level of lumbopelvic control in order to successfully complete the exercises, or that successful completion was limited by pain. The relatively brief (6-week) exercise programme undertaken here, may also have been insufficient stimulus for change in some people with chronic pain.

Higher body mass index (BMI) was associated with success following the exercise intervention in this study, and was a variable in the CPR derived by Stolze et al. (2012), but did not significantly influence change in disability following an imprecisely described physiotherapy intervention in another study (Mangwani et al., 2010). The current intervention may have positively influenced overweight participants by providing a manageable volume of exercise that contributed to improved mood, self-efficacy, and self-concept (Annesi, 2010), factors linked to recovery from LBP (Main et al., 2010).

4.2. Variables not included as predictors

Previous studies have also failed to identify a role of many of the variables not shown here to predict chronic LBP outcomes, including age, gender, LPB duration (Denison et al., 2004), spinal stiffness (Ferreira et al., 2009) or muscular endurance test scores (Mannion et al., 2001; Hicks et al., 2005), though not in all cases for trunk muscle endurance in relation to LBP disability (Enthoven et al., 2003; Evans et al., 2005). On the other hand, psychological factors such as fear of pain and movement, catastrophising, distress and depression, and fear avoidance beliefs, though not identified as predictors here, have been found to play a strong role in the development and maintenance or amelioration of LBP-related disability (Burton et al., 2004; Leeuw et al., 2007; Main et al., 2010; Picavet et al., 2002; Mannion et al., 2001). It is not clear why these variables did not enter predictive models in this study, but the deliberate recruitement of participants for an exercise trial might have resulted in a sample with less psychosocial antecedents for LBP than in some previous studies.

4.3. Single cohort design

With a single group design, findings must be interpreted cautiously because predictors identified could conceivably have been associated with spontaneous recovery (or failure to recover) that were not related to the Pilates exercise. Nonetheless, the predictors of beneficial changes in disability observed here (increased disability, gradual rather than sudden onset, poorer movement control indices, and higher BMI) are in the opposite direction to those associated with spontaneous resolution of chronic LBP. This tends to suggest that the intervention did drive the clinical effect, though this cannot be established definitively in the absence of a control group. Because of the paradoxical lack of aberrant motions on forward flexion being associated with treatment success, and asymmetrical straight leg raise being associated with treatment failure, the possibility is suggested of an alternative mechanism of action to improvement of conventional movement control deficits. The resolution of chronic LBP might be mediated by a complex balance of factors including cognitive, social, lifestyle, or other neuromuscular (O'Sullivan, 2012).

4.4. Limitations of study

A consistent shortcoming of CPR development studies for LBP is the small sample size. Several studies that derived CPRs for distinct treatment methods had 54–71 participants (Flynn et al., 2002; Fritz et al., 2004, 2007; Hicks et al., 2005), though more recently Stolze et al. recruited 96 (Stolze et al., 2012). Ideally, based on nine predictors entered into the regression models, 90 participants would have met minimum recommended ratio of variables to sample size (Peduzzi et al., 1996). Although we recruited only 55 participants, our follow-up regression procedure was undertaken with only five dichotomised variables, a step we consider allows greater confidence in the resulting predictors.

Nonetheless, in this exploratory study, some caution needs to be applied in concluding the lack of role of variables not retained in the final prediction rules, as we lacked sufficient statistical power to be fully confident.

4.5. Generalisability and further research

Participants actively volunteered for the study and only those who completed the intervention were included in the regression analyses. Therefore, the applicability of the derived CPRs is restricted to people who will actually complete an exercise programme. Adherence rates are commonly poor in exercise interventions (Jack et al., 2010), and it is important to identify, in advance, whether patients are likely to complete the programme.

It should be noted that the developed clinical prediction rules are not yet appropriate for use in a clinical setting. Controlled validation studies, and ideally impact studies, need to be conducted to determine the true value of these rules (Beattie and Nelson, 2006). The rules could be re-developed by including the most significant and sensible predictors from this study, identifying and including further potential predictors, and then determining which predictors are useful in a different population with an intention-to-treat protocol. Medium (3–12 months) and long term (>12 months) outcomes should also be assessed.

5. Conclusions

Two clinical prediction rules with moderate predictive ability were developed for a chronic LBP population following a 6-week, biweekly graded programme of movement control exercises. The rules showed that a combination of high disability levels, history of gradual onset of low back pain, absence of aberrant motions on forward bending and higher body mass index was best able to predict clinically important improvement in disability, while low levels of disability, history of sudden onset of low back pain, and differences between left and right active straight leg raise predicted failure to show clinically meaningful improvement. Follow-up studies are required to confirm these results in a wider population and over longer follow-up periods.

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Conflict of interest declaration

CH manages a private Pilates studio and provides personalised exercise consultation.

No other conflicts of interest.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jbmt.2018.06.007.

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