TITLE: A Randomized Controlled Trial of the Effects of Isolated Lumbar Extension Exercise on Lumbar Kinematic Pattern Variability during Gait in Chronic Low Back Pain

CONTRIBUTORSHIP STATEMENT

All listed authors contributions include the conception and design, acquisition of data or analysis and interpretation of data, drafting the article or revising it critically for important intellectual content, and final approval of the version published.

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CONFLICTS OF INTEREST

The authors have no conflicts of interest to declare.

ABSTRACT

Background: Chronic low back pain (CLBP) is a multifactorial condition with a variety of symptoms; one being abnormal gait. The lumbar spine and its musculature are important in controlling gait and in CLBP the lumbar extensors are often deconditioned. Because of this specific isolated lumbar extension exercise is often recommended. It was therefore of interest to examine its effects of upon gait variability.

Objective: To examine the effects of isolated lumbar extension resistance training upon lumbar kinematic variability during gait in participants with CLBP.

Design: Randomized controlled trial.

Setting: University Health, Exercise and Sport Science Laboratory

Participants: Twenty four participants with non-specific CLBP

Interventions: Participants were randomly allocated to a 12 week isolated lumbar extension exercise intervention (1x/week performing a single set to momentary muscular failure using a load equal to 80% max tested torque) or non-training control period.

Main Outcome Measurements: Lumbar kinematics during gait including angular displacement, kinematic waveform pattern (CV_p) and offset (CV_o) variability were examined using three dimensional analyses.

Results: No significant changes in displacement or CV_o were found as a result of the intervention. However, a small but significant reduction in sagittal plane CV_p (-20.90±43.53%, Effect Size = 0.48, p = .044) occurred indicating improved motor pattern replication through this movement plane.

Conclusions: Considering the role of the lumbar extensors in gait, and their common deconditioning in CLBP, an isolated lumbar extension resistance exercise intervention may reduce gait variability. These results suggest isolated lumbar extension exercise may specifically reduce sagittal plane variability, indicating improved motor pattern replication through this movement plane, perhaps due to the plane of movement utilized during the exercise.

KEY WORDS: Three Dimensional Analyses; Resistance Training; Strength; Disability; Motor Control

INTRODUCTION

Chronic low back pain (CLBP) is highly prevalent [1-4] with considerable costs worldwide [5-13]. However, in as much as 85% of LBP cases no specific patho-anatomical diagnosis is found [14]. More recently CLBP has been noted a multifactorial condition with a variety of associated symptoms [15,16]. One of these symptoms being abnormal gait [17-19]. Average movement amplitudes of the trunk and pelvis in CLBP participants do not usually differ from asymptomatic participants [18,20,21]. However despite this, CLBP participants do present differently in other aspects of lumbar spine movement; inability to adapt pelvis/trunk coordination phase differences during increased walking velocity [20-26], and greater stride-to-stride variability lumbar spine movement relative to the pelvis [18]. Lamoth and colleagues [24] suggest ability to deal with unexpected perturbations in movement is likely reduced. It is also suggested that deficiencies in gait control produce excessive stresses to the lumbar spine, perhaps contributing to CLBP [18]. However, recent review reports little evidence for walking itself being causally associated with CLBP [27]; thus the gait observed in CLBP might be justifiably considered a symptom instead.

Another common factor associated with CLBP is specific deconditioning (i.e. reduced strength/endurance, atrophy, and excessive fatigability) of the lumbar extensor musculature [28] with evidence suggesting it may be involved in abnormal gait in CLBP [20,23,29-35]. Healthy participants demonstrate relatively low stride-to-stride variability in lumbar kinematic patterns during level and incline gait [36]. However, greater stride-to-stride variability at the lumbar spine in all planes [18], greater frontal plane coordination variability of the pelvis/trunk [20,21], and more rigid transverse plane coordination variability of the pelvis/trunk [20,25,37] is reported in CLBP participants. This abnormal variability combines with poorer erector spinae activity adaptability to unexpected perturbations [29], or velocity changes [23]. In fact, findings from numerous studies suggest lumbar extensor dysfunction during gait in CLBP [20,23,29-31]. Hanada et al. [35] also report, though asymptomatic controls activated their rectus abdominus and internal oblique's greater compared with their lumbar extensors, the opposite was seen in symptomatic participants i.e. greater lumbar extensor activation compared to rectus abdominus and internal oblique's. More recent work suggests greater lumbar extensor activity in CLBP participants compared with controls [32], at a range walking velocities [33], and neither disability nor fear of movement is associated with this activity [32]. However, different coping strategies may be associated with greater activity (catastrophizing) or greater relaxation during double support (distraction) suggesting some cognitive influence over control of motor patterns [34].

Gait is normally quite robust in the face of lower limb muscular weakness [38]. The lumbar spine, however, helps drive human bipedal gait [39]. It is possible greater lumbar extensor activation, and altered lumbar spine kinematics in CLBP, is a manifestation of the commonly associated lumbar extensor deconditioning [28]. Greater activation in the face of fatigue due to deconditioning might be compensatory to maintain lumbar spine control during gait. Hart et al. [40] demonstrate inducing lumbar extensor fatigue impacts lumbar kinematics during running gait of healthy and CLBP participants. Arjunan et al. [41] also show greater lumbar extensor activity during running gait in CLBP. Indeed, prospective evidence suggests lumbar extensor deconditioning as a risk factor for low back injury and pain [28]. Thus, it may be responsible for development of abnormal gait variability in CLBP.

Exercise programs have shown success in improving aspects of gait variability in older individuals with improvement in part determined by strength gains [42]. Specific lumbar extensor exercise, however, is often used in CLBP [43] and thus may affect the associated lumbar spine kinematic gait variability. Varied exercise based interventions (Pilates, trunk extensions, stability exercise, transverse abdominus exercise) improveme gait control in CLBP participants [44-46]. However, more specific exercise for the lumbar extensors is isolated lumbar extension (ILEX) [47]. ILEX significantly improves lumbar extensor strength, pain and disability in CLBP participants [48-50]. Further, recent work reports improvement in ILEX strength from a strengthening program predicts improved gait endurance in CLBP participants [51]. ILEX however has yet to be examined for effects upon lumbar kinematics during gait. Taking this into consideration, the purpose of this study was to examine the effects of an ILEX exercise intervention upon lumbar kinematic variability during gait in participants with CLBP.

METHODS

Study Design

A randomized controlled trial design was adopted with one experimental group and a control group. The study was part of a wider investigation examining ILEX in CLBP participants published in part elsewhere [50]. Gait data were also collected as part of this study, though it was not hypothesized the different training groups (FULLROM & LimROM) would differ in this outcome. Data analysis revealed no differences between the two intervention groups for these outcomes and variables found to significantly improve here were similar between the two groups (see below). Thus here the two groups were combined to form a single training group. Strength,

pain and disability outcomes are reported elsewhere [50]. Here the gait data are described only. The study was approved by the NHS National Research Ethics Service, Southampton & South West Hampshire Research Ethics Committee B (REC Reference: 11/H0504/9).

Participants

Thirty eight participants (males n = 21, females n = 17) were initially identified and recruited by posters, group email and word of mouth from a University and the surrounding locality. Direct referral was also provided from a local private chiropractor in addition to posters in their practice. A power analysis described previously [50] showed that each group required 7 participants to meet the required power of 0.8 at an alpha value of $p \leq .05$. No previous work has examined effect sizes of the kinematic variables considered here and so, though considered adequately powered with respect to ILEX strength outcomes, there was possibility a type II error may result with respect to kinematic data. To reduce this risk, 5 kinematic trials were performed per participant, considered sufficient for adequate statistical power for kinematic data utilizing single subject statistical methods [52].

Inclusion criteria were as follows; participants suffered from current non-specific low back pain having lasted longer than 12 weeks [53] and had no medical condition for which resistance training would be contraindicated. Exclusion criteria were as follows; participants must have no medical condition for which movement therapy would be contraindicated. These included: acute (not re-occurring) low back injury occurring within the last 12 weeks, pregnancy, evidence of sciatic nerve root compression (sciatica), leg pain radiating to below the knee, paresthesia (tingling or numbness), current tension sign, lower limb motor deficit, current disc herniation, previous vertebral fractures or other major structural abnormalities. Participants were cleared as meeting the inclusion criteria and not exhibiting any of the exclusion criteria prior to involvement in the study by either their General Practitioner or the Chiropractor in the research group and provided written informed consent.

Figure 1 shows a CONSORT diagram highlighting participant numbers for enrolment, allocation, follow-up and analysis. After initial drop outs thirty one participants were randomized using an randomization program (Research Randomizer vs. 3.0) to one of three participant groups; FullROM training group who trained using a full range of motion (n = 12), LimROM training group who trained using a limited range of motion (n = 10), and a control group (n = 9). As noted, the two training groups were combined for analysis.

178 ***Equipment***

179 Isometric ILEX strength testing and training were performed using the MedX Lumbar Extension Machine (MedX,
180 Ocala, Florida; figure 2). The lumbar extension machine is reliable in asymptomatic [54] and symptomatic
181 participants [55], and valid in removal of gravitational effects [56] and pelvic movement [57]. Pain was measured
182 using a 100mm point visual analogue scale (VAS) [58], and disability measured using the revised Oswestry
183 disability index (ODI) [59]. Gait kinematic variables were captured at 500hz using a 10 MX T20 camera three
184 dimensional motion capture system (Vicon, Oxford) and analyzed using both Vicon Nexus software version
185 1.4.116 (Vicon, Oxford), MATLAB version R2012a (MathWorks, Cambridge) and Microsoft Excel version 2010
186 (Microsoft, Reading).

187

188 ***Participant Testing***

189 Isometric ILEX strength was tested twice, on separate days (at least 72 hours apart in order to avoid the effects of
190 residual fatigue or soreness) both before and after the intervention. The first test acted as familiarization and data
191 from the second test was used for analysis. Each test involved maximal voluntary isometric contractions. Details
192 of the full test protocol using the lumbar extension machine are documented elsewhere [54]. During the first and
193 second to last visit to the laboratory, before and after the intervention, participants completed the VAS and the
194 ODI. Gait data was collected using the Vicon system during the third visit and final visit to the laboratory both
195 before and after the intervention period. Gait data was collected at least one week after isometric ILEX strength
196 testing.

197

198 ***Three dimensional motion analyses***

199 A three dimensional approach was used for data collection. Ten cameras were set up and angled in a manner to
200 reduce hidden spots that might obscure data collection. The cameras identified reflective markers attached to the
201 participant and output three dimensional coordinates for each marker. Data were recorded for 5 walking trials
202 both pre and post intervention. Participants walked barefoot along a marked runway 8 meters in length at their
203 free walking speed. At least one full gait cycle was captured per trial.

204

205 ***Biomechanical Model***

206 The lumbar spine was considered from S1 to T12 relative to the pelvis and modelled as a rigid segment due to the
207 segments ranging S2 to T10 always bending laterally toward the support leg with little variation between segments

208 [60]. Lumbar spine data were collected using the model previously described by Schache et al. [61] shown to have
209 high overall repeatability of angular parameters [62].
210
211 ***Marker Set Up***
212 Reflective markers were placed over anatomical landmarks on the pelvis at both anterior superior iliac spines
213 (ASIS) and at the midpoint of the posterior superior iliac spine (PSIS). Reflective markers were also used upon a
214 thoracolumbar marker cluster similar to that used by Schache et al., [61,62]. As with the biomechanical model,
215 this marker set up has been previously described elsewhere [61,62]. The only alteration in this present study was
216 the use of a flexible based wand marker for the thoraco-lumbar cluster. Two additional markers were secured
217 equidistant either side of the midpoint of the wand markers base. This was placed over T12 with the mid-point of
218 the base located over the spinous process. The ASIS and PSIS were identified by palpation after identifying the
219 iliac crest and palpating along its length. T12 was first located and marked using the technique suggested in *Gray's*
220 *Anatomy for Students* [63]. This location was confirmed, whilst the participant was in a flexed standing position
221 supporting themselves upon a stool, by palpation and counting of the spinous processes from this marked point
222 down to the sacrum, and then double checked by counting back up to the marked spinous process. All markers
223 and the base of the thoracolumbar marker cluster were secured using double sided adhesive tape. Markers were
224 placed by the same investigator for all gait trials. Figure 3 shows the marker set-up used.
225
226 ***Kinematic Data***
227 Variability of angular kinematics of the lumbar spine about the three described axes relative to the pelvic segment
228 was of primary interest (i.e. movement of the thoraco-lumbar marker cluster with respect to the pelvic markers).
229 The Vicon Nexus software was used to run a Bodybuilder (Vicon, Oxford) code pipeline to calculate joint angles
230 as outputs using Cardan (Euler) angles. The angles were calculated in the following order; 1) sagittal, 2) frontal,
231 and 3) transverse. As with the biomechanical model, the Bodybuilder code used was the same as used by Schache
232 et al. [61,62]. Data were filtered using a low pass Butterworth filter (fourth order, cutoff frequency determined
233 for each individual participant as sum of residuals closest to zero using 4Hz, 6Hz, 8Hz, 10Hz, and 12Hz) and
234 normalized to percentage gait cycle corresponding to initial right heel contact (0%) and subsequent right heel
235 contact (100%). Heel contacts were identified as the lowest vertical displacement of a right heel marker. Stride
236 duration and length was also calculated using the horizontal displacement of the right heel marker from initial
237 right heel contact and subsequent right heel contact. Intra-subject variability in mean ensemble average was

calculated using coefficient of variation with pattern (CV_p) and offset (CV_o) variability calculated separately to account for the different information they provide; CV_o being the variability in the mean offset of the waveform determined by the reference frame used, identification of anatomical landmarks, markers and their configuration, whereas CV_p represents the variability in the waveform pattern and is more representative of repeatability of motor performance [64].

Participant Training

Training was conducted 1x/week for 12 weeks. This frequency of training significantly improves ILEX strength whereas overtraining can occur at greater frequencies for ILEX [65], and that 2x/week training offers no greater improvements [48]. Twelve weeks was chosen as strength improvement from ILEX training occurs largely within the first 12 weeks [66]. Both groups performed one set of variable resistance ILEX exercise. FullROM group used their full ROM while LimROM group only used the mid 50% of their individual ROM [50]. Load was 80% of max recorded ILEX strength and repetitions performed until momentary muscular failure to control intensity of effort [67] using a duration of at least 2 seconds concentric phase, 1 second hold in full extension and at least 4 seconds eccentric phase. Load was increased 5% next session once the participant could continue for over 105 seconds using their current load before failure.

Data Analysis

Eligibility for analysis required completion of 75% of the intervention. Twenty four participants' data (Males, n = 13; Females, n = 11) were available after attrition. This number combined with 5 trials per participant was sufficient for statistical power. Mean values for angular displacements, stride-to-stride intra-subject variability using CV_p and CV_o were calculated for lumbar spine kinematics relative to the pelvis across all three planes of movement. Baseline demographic data and changes in VAS, ODI and ILEX strength met assumptions of normality and homogeneity of variance and thus were compared between groups using an independent samples t-test. Kinematic data did not meet assumptions of normality or homogeneity of variance as is typical [68]. Thus non-parametric analysis was used and baseline data compared between groups using Mann Whitney-U exact test to check randomization succeeded for these variables. Examining the effects of the intervention, the independent variable was participant group (i.e. Combined training or Control) and dependent variables the absolute change from pre to post for kinematic variables. Wilcoxon Signed Ranks Exact test compared across the independent conditions. Perceived pain and disability were compared to consensus standards for minimal clinically important

change [69] (MCIC). Ostelo et al [69] proposed the MCIC for VAS as 15mm and for ODI 10 points. Further, effects sizes were calculated using Cohens *d* [70]. Statistical analysis was performed using SPSS statistics computer package (vs.20) and $p \leq .05$ set as the limit for statistical significance.

RESULTS

Participant Demographics

Participant demographics, pain, disability and ILEX strength data are shown in Table 2 for groups. Comparison between groups revealed similar demographic variables at baseline and only showed a significant difference in VAS score ($t_{(22)} = 2.420$, $p = .024$).

Effects of Intervention upon VAS, ODI, and ILEX Strength

Table 2 shows mean changes in VAS, ODI and ILEX strength in addition to effects sizes and 95% Confidence Intervals. The training group showed significant changes in VAS ($t_{(22)} = -3.651$, $p = .001$), ODI ($t_{(22)} = -4.831$, $p < .001$ and ILEX strength ($t_{(20)} = 3.641$, $p = .002$) compared with the control group. Effect sizes were also considered larger for the training group and VAS and ODI both met MCICs.

Effects of Intervention upon Kinematic Variables

Table 3 shows pre and post group data for displacement, CV_p and CV_o. Wilcoxon Signed Ranks Exact test revealed significant changes after the intervention only for sagittal plane CV_p ($W_{(16)}$, $Z = -1.728$, $p = .044$) in the training group only (The FullROM and LimROM groups made similar average improvements individually of -20.32% and -21.72% respectively) suggesting improvement in stride to stride waveform pattern replication. Figure 4 presents an example of the pre and post kinematic waveforms for one training group participant for both individual gait trials and also the mean ensemble average showing a reduced stride to stride variability (evidenced by the narrower standard deviations about the mean ensemble average).

DISCUSSION

A 12 week ILEX resistance training intervention produced significant reduction in sagittal plane variability during gait in CLBP participants. These findings potentially offer further understanding regarding the relationships between CLBP, gait variability and lumbar extensor deconditioning.

Lumbar kinematic variability during gait in CLBP participants may be a consequence of the lumbar extensor deconditioning frequently associated with this population [28]. This potential link is emphasized by the fact that lumbar extensor fatigue affects lumbar kinematics during gait [40]. It seems reasonable to conclude that deconditioning of the musculature associated with controlling gait in patients with CLBP might be partially responsible for altered motor control. [39,71-73] Our findings in this study tend to support this conclusion.

Previous studies offer support for exercise interventions improving aspects of gait variability including muscle activation [46], ground reaction force parameters [45] and displacements [44]. However, none have examined lumbar kinematic variability during gait, nor utilized specific exercise to isolate the lumbar extensors. Within the present study an intervention employing a highly specific form of exercise (ILEX) evidenced as most effective for conditioning the lumbar extensors was used [47]. The results indicate ILEX resistance training produced significant reduction in sagittal plane CV_p suggesting improved ability to replicate motor patterns in this plane during gait. Because ILEX may be an optimal approach for conditioning the lumbar extensors [47] it appears reasonable the results produced may be the result of addressing the specific deconditioning seen in CLBP [28].

However, the improvement in sagittal CV_p may suggest a specific intervention effect due to the plane of motion ILEX exercise is performed through. An exercise device similar to that used for ILEX also exists, which allows pelvic restraint for torso rotation through the transverse plane to be performed in isolation (Torso Rotation Machine, MedX, Ocala, Florida). Mooney et al. [74], demonstrated the latissimus dorsi and contralateral gluteus maximus follow a reciprocal activity relationship during gait, presumably contributing to control about the transverse plane. Mooney et al. [74] also examined activation during torso rotation exercise reporting abnormal activation patterns in symptomatic participants compared with controls. After a training intervention of progressive resistance training using the torso rotation device activation returned to normal levels of activity seen in asymptomatic participants. However, despite reporting EMG results for the latissimus and gluteus to clarify their role during gait, Mooney et al. [74] did perform pre and post intervention gait measurements to identify if any change had occurred in muscular control during gait. In light of the results of the present study it is suggested future research examine whether plane of movement specific training produces consequent plane of movement specific changes in lumbar spine control during gait i.e whether torso rotation improves transverse CV_p.

Though it seems reasonable the lumbar extensor conditioning effect from ILEX [47] might be the responsible for the sagittal CV_p changes reported, the effect of reduced pain or disability should also be considered. In a previous

report [50] and others [48,49] we show the ILEX intervention used produces significant and meaningful reductions in pain and disability. Thus this may be a factor responsible for the gait improvements. However, other evidence suggests pain presence may not be associated with gait variability [26,29,75]. Lumbar spine kinematics during gait appear complex and developed over time, with patterns evident before pain is experienced [75] and both induced pain and fear of pain produce little change in muscle activity in CLBP patients [29]. Recent studies have shown that, even those with previous history of CLBP who are currently asymptomatic, demonstrate abnormal gait patterns [21,76]. Considering the multifactorial nature of CLBP, this evidence suggests gait variability may be a symptom associated with CLBP that results in consequence of lumbar extensor deconditioning. However, it is possible that pain might not be primarily responsible for this findings, but it might be caused by the consequences of pain. Though neither disability nor fear of movement is associated with greater lumbar extensor activity during gait in CLBP [32], different cognitive strategies may be associated with greater activity (catastrophizing), or greater relaxation during double support (distraction), suggesting influence of pain consequences [34]. This consideration requires further investigation.

Study Limitations

The limitations of the present investigation should be noted. The clinical value of the significant change in sagittal CV_p (-20.90±43.53%) is not wholly clear due to the large variability. If the effect size is calculated (0.48), the magnitude of change is considered small [70]. In addition, we are unaware of whether any data on asymptomatic participants exists for these outcomes, thus making the determination of clinical significance difficult. Finally, though Schache et al. [62] have shown high reliability for angular data for the model adopted in this study, we did not conduct our own reliability analysis.

CONCLUSIONS

The results of this study provide novel information on lumbar spine kinematic variability during gait in CLBP. A 12 week ILEX resistance exercise intervention significantly reduced sagittal plane CV_p suggesting improved motor pattern replication. These findings are important as they demonstrate that improvements may be possible in various factors typically associated with CLBP through use of ILEX exercise.

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FIGURES

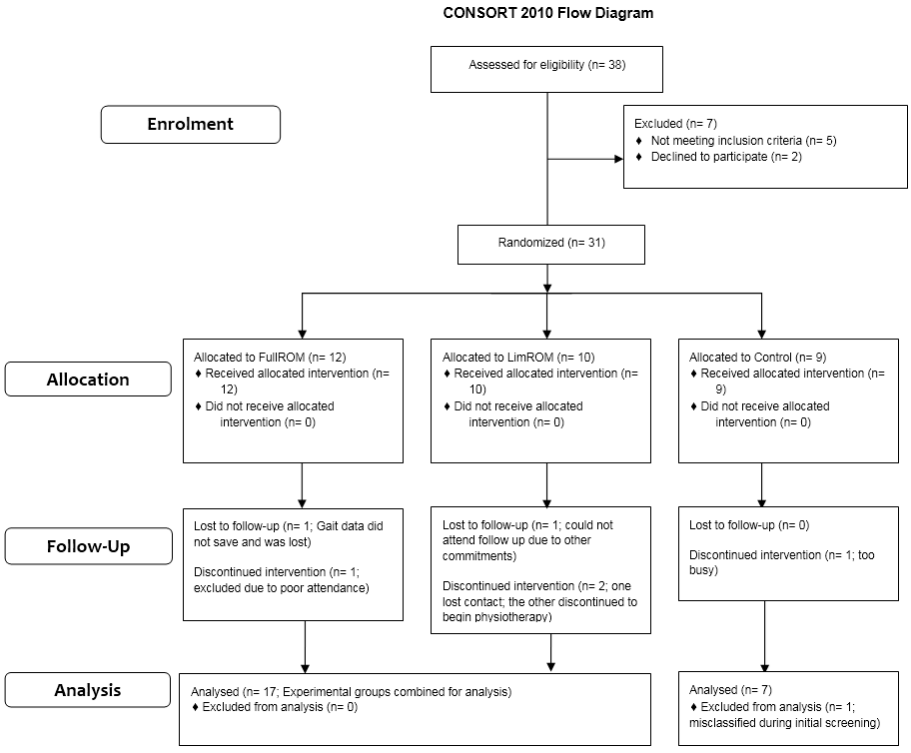
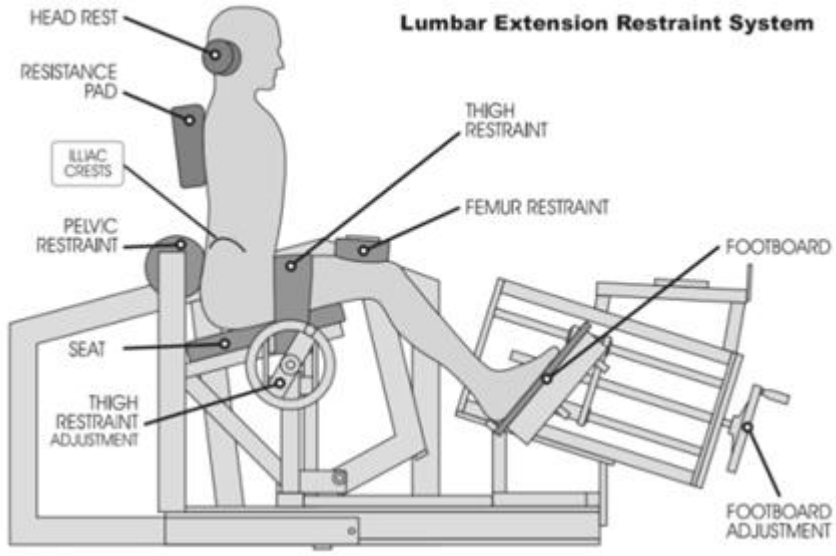


Figure 1. CONSORT diagram showing flow of participants through the study



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520 Figure 2. MedX Lumbar Extension Machine Restraint System (Reproduced with permission from MedX

521 Corporation)

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523 Figure 3. Marker set-up

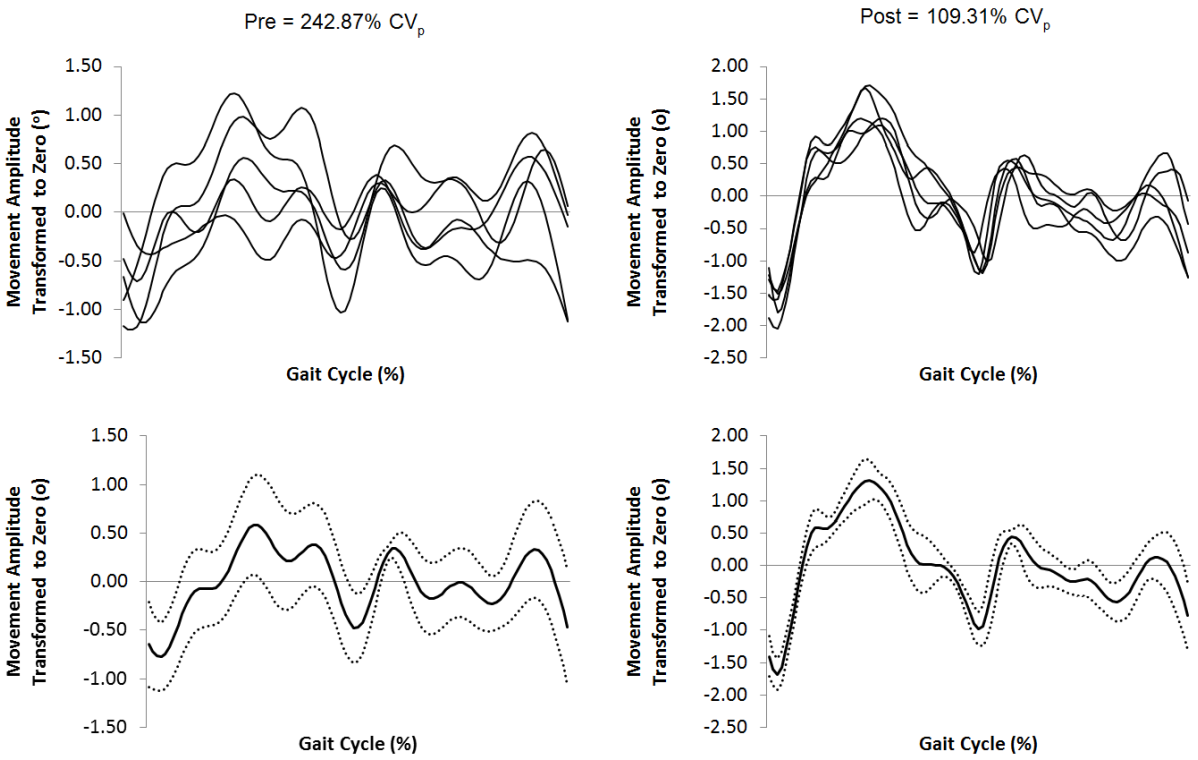

Figure 4. Example of Training Group Pre (left) and Post (right) Lumbar Kinematic Pattern Variability; top graphs show individual trials kinematic waveform patterns and bottom graphs shows mean ensemble average (± standard deviation; dotted line) for these trials; CV_p = Waveform pattern variability.

TABLES

Table 1. Baseline group demographics.

	Training (n = 17)	**Control (n = 7)**	***p***
Age (years)	47±13	42±15.	.645
Stature (cm)	171.90±9.26	180.82±7.70	.076
Body Mass (Kg)	75.00±15.49	85.48±18.26	.324
BMI (Kg/m^2)	25.12±3.10	25.94±4.41	.899
Symptom Duration (years)	14±11	12±11	.800
VAS (mm)	47.26±24.09	19.2±15.51	.024
ODI (pts)	34.71±12.69	26.2±7.27	.158
ILEX Strength (Nm)	177.80±83.80	192.21±67.60	.691

BMI = Body Mass Index; VAS = Visual Analogue Scale; ODI = Oswestry Disability Index; ILEX = Isolated Lumbar Extension

Table 2. Changes in VAS, ODI, and ILEX strength as a result of the ILEX resistance training intervention.

Outcome		Change	95%CIs	Effect Size
VAS (mm)	Training	-23.65±21.59	-35.82 to -10.58	-1.10
	Control	10.29±18.11	-6.46 to 27.03	0.57
ODI (pts)	Training	-17.06±6.71	-20.13 to -12.67	-2.54
	Control	-1.71±7.95	-9.07 to 5.64	-0.22
ILEX Strength (Nm)	Training	41.49±30.51	24.60 to 58.39	1.36
	Control	10.29±18.11	-15.25 to 9.67	-0.21

95%CIs = 95% Confidence Intervals; VAS = Visual Analogue Scale; ODI = Oswestry Disability Index; ILEX = Isolated Lumbar Extension

Table 3. Pre and post ILEX resistance training intervention kinematic data

	Displacement (degrees)			CV_p (%)			CV_o (%)		
	Frontal	Sagittal	Transverse	Frontal	Sagittal	Transverse	Frontal	Sagittal	Transverse
Training									
Pre	10.61±3.74	3.92±1.20	8.85±2.72	41.95±16.62	111.99±42.64	46.49+20.57	27.48±18.34	103.94±52.78	41.69±28.15
Post	10.80±2.88	4.31±1.37	9.41±3.26	39.35±12.72	91.09±28.27*	48.20±24.02	25.87±15.02	87.95±41.10	42.35±25.28
Control									
Pre	8.15±1.94	4.13±1.78	6.91±7.87	52.65±19.23	92.95±27.07	33.41±11.74	32.30±29.09	66.33±69.07	14.15±5.46
Post	7.25±2.31	3.80±1.54	8.86±2.32	56.45±11.82	89.51±26.63	40.25±20.83	44.59±46.13	85.91±39.78	31.66±27.27

*Denotes significant change from pre to post (p = .044); CV_p = Waveform pattern variability; CV_o = Waveform offset variability