OBJECTIVE: The purpose of this pilot study was to use a multidimensional model to evaluate deficits in patients with low back pain (LBP) over the course of a 12-week rehabilitation program using the Swiss ball.

METHODS: A within-subjects, repeated-measures design based at the University exercise training clinic was used. Twenty patients with chronic nonspecific LBP (12 men, 8 women; symptom duration, 4.8 years; 38.8 ± 12.1 years old; height, 1.76 ± 0.06 m; weight, 76.15 ± 7.21 kg) participated in this study. Self-report measures were the Oswestry Disability Index, Visual Analog Scale, Medical Outcomes 12-Item Short Form Health Survey, and Self-Efficacy For Exercise Scale. Physiologic measures were electromyography measurement of feedforward muscle activation, flexion relaxation phenomenon, myoelectric fatigue, endurance capacity measured by the Sorenson test, and a modified sit-up test. Individuals performed 12 weeks of progressive exercise periodized every 4 weeks using a Swiss ball. Outcome measures were assessed at baseline, 4 weeks, 8 weeks, 12 weeks, and at a 3-month follow-up. Repeated-measures analysis for variance for time differences and regression analysis for variance in Oswestry scores were performed.

RESULTS: The Oswestry score for self-reported disability significantly decreased over the intervention (F_{4,14} = 19.456, P < .001). Significant improvements in pain and disability maintained to the 3 months of follow-up. There were significant changes in perceptions of physical and mental well-being, erector spinae fatigue, and flexion relaxation measures. Change in flexion relaxation explained 38% of the improvement in Oswestry scores at the 12-week measurement.

CONCLUSIONS: This study showed that the Swiss ball may be successfully used in a rehabilitation context for patients with LBP. This pilot study has used a novel approach to assess improvements during a rehabilitation program, which may be used in the future to explain differences between different treatment modalities. (J Manipulative Physiol Ther 2006; 29:550-560)

Key Indexing Terms: Low Back Pain; Exercise Therapy; Rehabilitation; Electromyography

Although the performance of structured exercise can improve the pain levels and functional capacity of individuals with nonspecific low back pain (LBP), there is no clear consensus on the most effective exercise protocol for this group. Protocols that have been used in this context include flexion-extension movement modalities, general aerobic conditioning, strength conditioning, stretching, core stability exercise, and basic isometric conditioning.

To determine which interventions are most effective, a relevant set of outcome domains needs to be used, which will afford the identification of possible explanations for differences in treatment protocol efficacy. In addition, a valid assessment model will explain why a subgroup of patients with LBP may improve with one protocol but not with another. Bombardier identified a core set of patient-based outcome measures comprising 5 domains: back-specific function, generic health status, pain, work disability, and patient satisfaction. A recent review of the evidence for exercise and LBP used the Bombardier model to assess the suitability of outcome assessments for different LBP rehabilitation programs. We note that a relevant domain, which is lacking from the Bombardier model, relates to neuromuscular deficits found in LBP individuals.

Motor control deficits in the trunk musculature of individuals with LBP have been reported, yet very little research exists on the effect of exercise on deficits in neuromuscular function. In their seminal article, Hodges and...
Richardson\textsuperscript{17} found that individuals with LBP exhibited delayed activation of the transversus abdominis muscle before rapid upper limb movements when compared with healthy controls. It has also been shown that individuals with LBP have an impaired ability to consciously contract transversus abdominis and that this is improved with specific abdominal stabilization training.\textsuperscript{7,18} However, there is currently no evidence regarding whether delayed abdominal activation before rapid limb movements can be modified by an exercise rehabilitation program.

Deficits in the flexion-relaxation (FR) phenomenon are another reported problem of LBP. The FR phenomenon is the electrical silence of the erector spinae muscles that is observed during full forward-trunk flexion\textsuperscript{19}; it has been shown that this relaxation is absent in individuals with LBP. A recent article was the first to show that absence of the FR phenomenon in LBP individuals can be influenced by an exercise protocol.\textsuperscript{20}

One way of potentially altering neuromuscular recruitment patterns is to perform exercises on an unstable surface.\textsuperscript{21-23} The Swiss ball is a device commonly used in the recreational training environment, yet its application in a rehabilitation setting has received little empirical attention. Research has found that use of the Swiss ball increased the activity of the rectus abdominis in comparison with muscle activity on a stable surface.\textsuperscript{24} Anderson et al\textsuperscript{25} have conducted a series of investigations that show changes in muscle activity and force output during exercises performed on a Swiss ball. No significant difference in electromyographic (EMG) activity of the pectorals, triceps, latsissimus dorsi, and rectus abdominis was found when performing maximal isometric chest presses under stable and unstable conditions. Maximum isometric force was decreased by 60\% with the unstable base.\textsuperscript{25} Leg extensor and plantarflexor activity was decreased with exercises performed in the unstable environment, whereas unstable force production was also less than on the stable surface.\textsuperscript{26} In contrast to these results, upper lumbar, lumbosacral erector spinae, abdominal, and soleus activity was increased when performing squats under unstable conditions with the same submaximal load.\textsuperscript{27}

The purpose of this pilot study was to use a multidimensional model to evaluate deficits in patients with LBP over the course of a 12-week rehabilitation program using the Swiss ball. Three outcome profiles were used, 2 based on the recommendations of Bombardier\textsuperscript{15} and a third based on neuromuscular deficits known to be associated with LBP. The physical profile measured basic anthropometric and endurance characteristics of the abdominal and lumbar muscles; the psychological profile incorporated assessment of pain and general well-being, and the neuromuscular profile measured the activation of the deep abdominals during rapid limb movement and the FR phenomenon.

This study has 2 novel aspects. First, it will provide information regarding the effects of Swiss ball training on individuals with LBP. We are not aware of any other studies that have evaluated the application of the Swiss ball in a rehabilitation protocol. Second, by virtue of the multidimensional outcome measures used, including the inclusion of a neuromuscular domain, it will enable determination of which specific domains and processes make significant contributions to any demonstrated improvement(s) in the study participants.

**Methods**

**Subjects**

Twenty patients were recruited from general medical practitioners, gym goers, chiropractors, and physiotherapists by personal contacts and referrals as well as television and newspaper advertising. The inclusion criteria were men and women 18 to 65 years of age who had experienced back pain for at least 12 weeks and had not received specific abdominal stabilization training or spinal manipulation nor performed an organized regimen of Swiss ball training within the last 3 months. Exclusion criteria were severe postural or skeletal abnormalities, obvious neuromuscular disorder, or spinal damage, as identified by magnetic resonance imaging, plain film radiographs, or any Accident Compensation Corporation red flags.\textsuperscript{28} There were 12 men and 8 women with a symptom duration of 4.8 years. The mean age of subjects was 38.8 ± 12.1 years, mean height was 1.76 ± 0.06 m, and the mean weight was 76.15 ± 7.21 kg. All patients gave informed written consent. The human subjects ethics review board of the University of Auckland, New Zealand, approved this study.

**Assessment Procedures**

Assessments for the patients were carried out by an independent examiner. The assessments were carried out at 0, 4, and 12 weeks during the intervention and at a 3-month follow-up session.

**Training Intervention**

Exercises were taught to the patients by an experienced exercise scientist, with a postgraduate qualification in exercise rehabilitation. Exercises were performed 3 times per week for a total of 12 weeks. The exercise program was periodized every 4 weeks to progressively increase the training stimulus (Fig 1). Swiss ball exercises involved in the training program have been previously investigated to determine that muscle activity is different from performing the same exercise on a stable surface.\textsuperscript{24} The exercise progression was based on the classic linear model where the initial period involved low-intensity exercises performed with higher repetitions.\textsuperscript{29} For the first 4 weeks, the prescription (based on minimum and maximum targeted levels of exercise) was 2 to 3 sets of 8 to 10 repetitions for each exercise. For the rest of the training intervention, the targeted training range was for 2 to 3 sets of 6 to
<table>
<thead>
<tr>
<th>0-4 weeks (isometric focus)</th>
<th>4-8 weeks (controlled concentric/eccentric)</th>
<th>8-12 weeks (dynamic exercises)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
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<td><img src="image13.png" alt="Image" /></td>
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<td><img src="image15.png" alt="Image" /></td>
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<tr>
<td><img src="image16.png" alt="Image" /></td>
<td><img src="image17.png" alt="Image" /></td>
<td><img src="image18.png" alt="Image" /></td>
</tr>
</tbody>
</table>

**Fig 1.** Exercises used in the 12-week intervention. The exercises were progressed based on measured EMG activity of the abdominal and back muscles, with lower relative intensity exercises in the first 4 weeks and higher relative intensity exercises in the last 4 weeks.

8 repetitions for each exercise. The program progressed to exercises of greater intensity performed with lower repetitions. From the 4-week point, both groups performed the same exercises using the Swiss ball. No resistance training using weights was allowed during the course of the training intervention. The range of sets and repetitions was based on the ability to individualize the workload for each patient based on their physical capacity. This was
adjusted at each weekly session by the trainer who supervised the program. Trainers involved in this study had at least an undergraduate degree in the sport and exercise science discipline.

Partial supervision of the exercise program was carried out over the course of the 12-week training intervention. Once per week, each subject was required to meet at the university training center to perform their required program under direct supervision of the trainer to ensure that the correct techniques were being performed. In addition, training diaries were filled in by the patients. Total workload, based on the number of repetitions performed, was filled in for each set performed for each exercise for each exercise session performed by the patient. This workload, as well as total physical activity (hours spent walking, cycling, playing sport, or participating in other physical leisure activities) was collected at each 4-week assessment point throughout the training intervention.

Outcome Measures

**Functional capacity.** Functional capacity was assessed using the Oswestry Disability Index (version 2). This is a 10-item evaluation of a patient’s impairment relating to their back pain and presents a score out of 50, which is converted to a percentage.30,31

**Psychological profile.** Pain was evaluated using the Visual Analog Scale (VAS). The VAS was based on evaluating the patients’ pain experienced within the last week with a 10-cm line anchored to the left (with no pain) and to the right (with worst pain). Self report of physical and mental well-being was assessed with the Medical Outcomes 12-Item Short Form Health Survey (SF-12).32,33 The Self-Efficacy For Exercise Scale was also used. This assessment was to assess the patient’s beliefs in their ability to exercise 3 times per week, fulfilling the requirements of the program shown to them for 40+ minutes per session over the next 4 weeks.34,35

**Neuromuscular profile.** Surface electromyography was used to evaluate fatigue of the back muscles, the FR phenomenon, and feedforward abdominal activation before rapid limb movements. Pairs of Ag/AgCl surface electrodes (3M Red Dot, 2-cm diameter, applied with center-center distance of 3 cm; 3M Health Care, Neuss, Germany) were applied to the muscles of interest for each measurement. Electromyographic activity was recorded using a GRASS model 15 data acquisition system (GRASS, West Warwick, RI) and digitized with a National Instruments analog to digital card (Austin, Tex) (common mode rejection ratio of 90 dB at 60 Hz, input impedance of 100 MU, 16-bit A/D conversion), sampled at 2000 Hz into a Pentium III computer system (Intel Corporation). The raw signal was band-pass filtered between 10 and 1000 Hz.

**Flexion-relaxation procedures.** Pairs of surface electrodes were applied to the right erector spinae (located at the level of L4-L5), gluteus medius (electrodes located inferior to the iliac crest, oriented obliquely along the palpated muscle), and biceps femoris (electrodes positioned half the distance from the gluteal fold to the center of the knee joint, oriented along the longitudinal axis of the palpated muscle).

The patients stood with their arms by their side and their feet shoulder width apart. The position of the feet was marked for consistency between trials. The subject was required to bend forward in 3 seconds with their hands by their sides until

![Fig 2. Electromyographic data demonstrating the flexion relaxation phenomenon. Each of the movement phases are separated into the 3-second segments. Note the significantly greater activity during the reextension phase compared with the flexion phase.](image-url)
they could bilaterally touch the lateral malleolus of the ankle joint. The subject was not restrained during this movement. The subject was then required to hold at the fully flexed position for 3 seconds. The reextension phase involved the subject moving back to the normal upright position in a 3-second movement. A counted time signal coordinated with the recording of the movement phases was used to pace the movement (Fig 2). Sufficient practice was provided to ensure that the correct pacing and familiarization with the procedures was achieved. During practice, a marker was applied to the subject if the lateral malleolus could not be reached by the subject to indicate where the end of the flexion phase was. Three trials were performed by each patient with 1 minute of rest between each trial.

The following readings were taken from the EMG recordings (Fig 2), based on the calculated root mean square (RMS, 50-millisecond period) of the raw signal:

A. The RMS of the maximal activity for 1 second during the forward flexion phase
B. The RMS of the maximal activity for 1 second during the fully flexed phase
C. The RMS of the maximal activity for 1 second during the reextension movement.

For the evaluation of FR, the FR ratio (FRR) was used for this study. The FRR was calculated by dividing the maximal activity measured during either phase A or C by the activity measured during phase B. The mean of the 3 trials performed was used to determine the FRR for each muscle for each subject. Previous research into the FR response has also used multiple trials to establish the most accurate measurement possible.

Feedforward muscle activation procedures. Pairs of surface electrodes were applied to the right and left sides of the abdominal wall in a site that has been defined as representing the activity of the internal obliques and transversus abdominis muscles. Briefly, the placement of the lateral electrode for each pair is located 2 cm medial and 2 cm inferior to the anterior superior iliac spines. This site is not positioned on the inguinal ligament and does not overlap either the fibers for the rectus abdominis or external oblique muscles. The respective fibers for the anterior, medial, and posterior deltoid were also prepared because these are the prime movers for the shoulder flexion, abduction, and extension movements performed in this study.

For the shoulder movement tasks, the patient was required to stand in a position with the feet placed shoulder width apart. Five repetitions of each shoulder movement were performed with the arm in the sagittal plane. Each repetition was performed as fast as possible in response to a light signal that was preceded by a warning stimulus. A random period was generated by the computer for the signal to move between 0.5 to 1 seconds after the warning stimulus. Previous research found that the limb movement velocity of patients with LBP was not different from normal controls. The patient was required to “breathe and relax” between each trial. A rest period of 3 to 5 minutes was provided between each set of shoulder movements. The latency between the onset of the abdominal muscles and the deltoid prime mover formed the basis of the analysis for this task. The mean latency for the right and left abdominal signals was calculated for the 5 trials performed for each movement (Fig 3).

The determination of the muscle onset was performed using an algorithm written in LabVIEW. The EMG signal for each channel was digitally smoothed using a Butterworth low-pass filter (fourth order, 100 Hz). The integrated profile technique was used to determine the onset point for each muscle, as detailed by Allison. Briefly, this technique involves comparison of the amplitude normalized integral of the signal to a time normalized curve. The maximum difference between these 2 functions represents muscle onset. The analysis window was selected from 150 milliseconds before, and 150 milliseconds after, the approximate...
visual onset of the deltoid signal. A muscle onset before the 150-millisecond window would indicate premeditation of the movement command. No trials were rejected because of premeditated muscle activity. Feedforward muscle activation has been defined as muscle activity that is not a reflex to the limb movement. The criterion for feedforward muscle activation was established at 50 milliseconds after the activation of the prime mover for shoulder movements. It has been shown that patients with LBP exceed this criteria during rapid shoulder movements.

Physical profile. Basic anthropometry was collected from each subject at every assessment session. The height and weight of each subject was measured for calculation of the body mass index (kg/m²). Hip and waist girths were collected from each subject for calculation of the hip/waist ratio. High waist girths are negatively associated with LBP in both men and women.

The Sorenson lumbar endurance test was used to evaluate the isometric endurance (in seconds) of each subject’s lumbar extensor muscles. Briefly, the hips and legs of the patients were stabilized on a cushioned bench with the trunk allowed to hang freely. The patients were required to maintain an extended position parallel to the lower limbs and the ground for as long as possible. Before commencing the test, the subjects were familiarized with the test position by supporting themselves with both hands on a stable surface beneath them then a single hand beneath them. The subjects were also required to practice the test position for 2 to 3 seconds so that they were familiar with the test position before conducting the endurance test.

A partial curl-up was administered to assess abdominal muscular endurance. This involves the performance of a controlled curl-up (metronome set to 50 beats per minute) in a continuous manner to a maximum of 25 in a 1-minute test period. Details regarding the performance of this test are provided elsewhere.

The spectral compression of the EMG signal measured from the back muscles was also used as an objective measure of fatigue. The subject was required to maintain a 30-second isometric contraction in the same position as the Sorenson endurance test. This was broken down into 30 1-second epochs of signal. Fast Fourier transforms (512-point Hamming window, 50% overlap) were used to produce an average power periodgram for every second of the contraction. The median frequency for each periodgram was calculated as the frequency that divided the area of the power spectrum in half. The rate of muscle fatigue was then estimated from the slope of a regression fit line of the median frequencies calculated over the course of the 30-second contraction.

Statistical Analysis

SPSS version 11.5 (SPSS, Inc, Chicago, Ill) was used for the data analysis. A repeated-measures analysis of variance (ANOVA) was used to determine the change in each variable over the assessment period (0, 4, 12, and 3 months) throughout this study. Multiple comparisons between the time points were performed with Bonferroni adjustment. A multiple linear regression was used to model the variance in

### Table 1. Data presented for the variables representing the psychological profile of the patients during the rehabilitation program

<table>
<thead>
<tr>
<th>Measure</th>
<th>F value</th>
<th>0</th>
<th>4 wk</th>
<th>8 wk</th>
<th>12 wk</th>
<th>3 mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pain VAS (%)</td>
<td>5.412**</td>
<td>47.39 ± 23.72</td>
<td>32.11 ± 24.78</td>
<td>22.61 ± 17.53</td>
<td>23.94 ± 19.71</td>
<td>20 ± 15.82</td>
</tr>
<tr>
<td>Physical well-being (SF-12)</td>
<td>5.232*</td>
<td>44.15 ± 6.86</td>
<td>47.30 ± 9.56</td>
<td>51.43 ± 7.93</td>
<td>48.25 ± 7.46</td>
<td>48.78 ± 7.29</td>
</tr>
<tr>
<td>Psychological well-being</td>
<td>3.814**</td>
<td>48.45 ± 9.22</td>
<td>49.7 ± 7.9</td>
<td>51.24 ± 6.79</td>
<td>55.77 ± 3.77</td>
<td>51.59 ± 6.7</td>
</tr>
<tr>
<td>Self-Efficacy for Exercise Scale (%)</td>
<td>1.587</td>
<td>90.64 ± 8.79</td>
<td>83.75 ± 17.24</td>
<td>89.11 ± 7.71</td>
<td>85.69 ± 18.88</td>
<td>81.08 ± 16.85</td>
</tr>
</tbody>
</table>

* P<.05.
** P<.01.

### Table 2. Flexion-relaxation ratio results calculated for the muscle signals collected in this study

<table>
<thead>
<tr>
<th>Muscle</th>
<th>F value for comparison between time points</th>
<th>0</th>
<th>4 wk</th>
<th>8 wk</th>
<th>12 wk</th>
<th>3 mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erector spinae</td>
<td>5.57*</td>
<td>3.26 ± 3.43</td>
<td>4.75 ± 3.26</td>
<td>7.03 ± 3.36</td>
<td>6.53 ± 3.34</td>
<td>4.7 ± 2.7</td>
</tr>
<tr>
<td>Gluteus medius</td>
<td>3.615**</td>
<td>1.61 ± 0.69</td>
<td>2.39 ± 1.7</td>
<td>2.42 ± 1.73</td>
<td>2.46 ± 1.59</td>
<td>2.58 ± 1.37</td>
</tr>
<tr>
<td>Biceps Femoris</td>
<td>1.046</td>
<td>2.41 ± 1.94</td>
<td>3.26 ± 1.82</td>
<td>3.17 ± 1.74</td>
<td>3.32 ± 1.75</td>
<td>3.13 ± 1.62</td>
</tr>
</tbody>
</table>

* P<.01.
** P<.05.
functional capacity (change in Oswestry) by the variables identified as changing over the time course of the study from the ANOVA procedure. A separate regression model was performed for each time point where significant changes in the independent variables were found. The significance of this study was set at $P < .05$.

### RESULTS

Two patients withdrew from this study. One female patient was involved in a motor vehicle accident and sustained a significant whiplash injury, and 1 male patient chose to pursue a different course of treatment that was outside the parameters of continued involvement in this study. Both patients withdrew in the 4- to 8-week period of the study. Therefore, the statistical analysis was conducted on the remaining 18 subjects who completed the full 12-week training intervention.

#### Change in Disability

The Oswestry score for self-reported disability significantly decreased over the intervention ($F_{4,14} = 19.456, P < .001$). All time points were identified as significantly lower scores compared with baseline (Fig 4). From the 8-week time point, there were no further significant reductions in Oswestry score.

#### Psychological Profile

As shown in Table 1, there was a significant decrease in pain intensity over the intervention period ($F_{4,14} = 5.412, P < .01$). By the 8-week point, the pain intensity was significantly decreased from baseline, and this did not change for the 12-week and 3-month measurements, which remained significantly decreased from baseline. There was no significant change in exercise self-efficacy scores throughout the intervention ($F_{4,14} = 1.587, P = .23$). There was a significant increase for the SF-12 self-perception of physical well-being component score ($F_{4,14} = 5.232, P < .01$). The 8-week score for this was significantly different from the baseline score only. There was also a significant increase over time for the SF-12 self-perception of mental well being component score ($F_{4,14} = 3.814, P = .027$). The score at the 12-week measurement was significantly different from all other time points.

#### Neuromuscular Profile

Table 2 shows the significant changes in the FRR calculated for the erector spinae over the intervention period ($F_{4,14} = 5.57, P < .01$). The ratios calculated for the erector spinae at the 8- and 12-week points were significantly different to both the baseline and 3-month follow-up measurements. There was no significant difference between the baseline and 3-month results for the erector spinae FRR. The FRR calculated for the gluteus medius muscle showed a significant increase over time ($F_{4,14} = 3.62, P = .032$), with the 3-month follow-up identified as being significantly different from baseline. There was no change in the FRR for the biceps femoris over the course of the intervention ($F_{4,14} = 1.046, P = .49$). There was no difference over time for the latency results measured for either the right or left transversus abdominis/internal oblique for any movement direction. The latency response measured from the patients exceeded the criteria for feedforward activation of 50 milliseconds after the deltoid prime mover (TA/IO).

#### Physical Profile

There was no significant change from baseline for the hip and waist measurements (hip circumference, 98.11 ± 4.28 cm; waist circumference, 81.72 ± 8.22 cm) and body mass index measures (height and weight) (Table 3). There was no change in the number of sit-ups the patients could perform over the course of the intervention ($F_{4,14} = 1.734, P = .199$). Neither was there a change in the raw time recorded for the Sorenson endurance test ($F_{4,14} = .197, P = .936$). There was a significant improvement in the rate of myoelectric fatigue measured with spectral rate of compression during an isometric contraction ($F_{4,14} = 6.357, P = .004$). The rate of fatigue measured at the 12-week point was significantly different from the baseline and 3-month follow-up results. A more positive score reflects a lower rate of fatigue during the contraction.

#### Regression Models for Changes in Oswestry Disability Index Scores

Two separate regression models were set up to determine if the variables that changed significantly could account for
the change in Oswestry Disability Index scores (Table 4). At the 8-week point, no single variable could be identified as being able to explain the variance in Oswestry scores. However, by the 12-week point, the neuromuscular domain, specifically the change in the FRR for the erector spinae, explained 38% of the changes in Oswestry score for the same period (Table 4).

**DISCUSSION**

**Changes in Disability**

The decrease in the Oswestry Disability Index score over the first 8 weeks showed that the exercise program was effective in improving self-reported functional capacity. These changes were maintained to the 3-month follow-up assessment. This result showed that the use of the Swiss ball as the mode of exercise may lead to positive results in a rehabilitation program. An interesting question must be raised about the lack of decrease in the Oswestry score after the 8-week measurement. This suggests that the program was an insufficient stimulus after this point for further improvements. The concept of periodization within an exercise program is to facilitate progressive functional adaptation of the tissues. Within this parameter of a training program, intensity, frequency, type of exercise, and time spent training are the variables to manipulate. After the 8-week period the only 1 of these variables manipulated was the intensity of the exercise. This may have been insufficient to continue to make physical gains throughout the rest of the program and may potentially explain the lack of improvement after the 8-week assessment. The results of this study suggest that for the initial 8 weeks of an exercise rehabilitation program for LBP patients, exercise using the Swiss ball is sufficient to facilitate improvements. What is important to note is that the improvement in the Oswestry score was maintained to the 3-month follow-up. After the 3-month follow-up, a follow-up of the patients was made by phone to determine whether any had purchased their own Swiss ball since the end of the 12 weeks. Only 2 of the patients reported that they had purchased a Swiss ball since the cessation of the 12-week intervention.

A further consideration for why there was no improvement after 8 weeks may be that the initial improvements were simply a regression to the mean disability level for the subjects in this study. This means that the initial disability level they reported was higher than it normally is and the improvement only reflects a more accurate reporting of their disability level. Another reason for why there was no improvement after 8 weeks is the lack of an overall whole body training stimulus. This is especially relevant for the hamstrings muscle groups, which had no significant functional change as measured by the FR response. The hamstring muscles are responsible for maintaining the posterior pelvic tilt and are therefore another important muscle in the area of lumbopelvic stability. It may be possible that the lack of a sufficient training focus for muscles, such as the hamstrings, prevents further improvements in disability after the 8-week point.

**Psychological Changes During the Intervention**

The decrease in back pain intensity showed a similar trend to the decrease in the self-reported disability. Scores on the

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**Table 3. Physical profile results collected during the study**

<table>
<thead>
<tr>
<th>Measure</th>
<th>F value</th>
<th>0</th>
<th>4 wk</th>
<th>8 wk</th>
<th>12 wk</th>
<th>3 mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sit-ups (no.)</td>
<td>1.734</td>
<td>24 ± 1.5</td>
<td>24.8 ± 0.4</td>
<td>24.9 ± 0.2</td>
<td>25</td>
<td>24.9 ± 0.3</td>
</tr>
<tr>
<td>Sorensen (s)</td>
<td>0.197</td>
<td>142.6 ± 42.8</td>
<td>146.8 ± 44.8</td>
<td>145.7 ± 39</td>
<td>144.8 ± 36.1</td>
<td>141.7 ± 45.8</td>
</tr>
<tr>
<td>MF (Hz sec⁻¹)</td>
<td>6.36*</td>
<td>−.45 ± .40</td>
<td>−.36 ± .25</td>
<td>−.24 ± .20</td>
<td>−.14 ± .12</td>
<td>−.42 ± .25</td>
</tr>
</tbody>
</table>

MF indicates median frequency calculated from the EMG power spectrum.

* P < .01.

**Table 4. Results of the multiple linear regression analysis for the independent variables that showed a significant change to the 8- and 12-week time points**

<table>
<thead>
<tr>
<th>Variables in model</th>
<th>Adjusted $R^2$</th>
<th>F value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Changes to the 8-wk time point</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Psychological domain: VAS, SF-12 PCS</td>
<td>0.10</td>
<td>1.99</td>
<td>.17</td>
</tr>
<tr>
<td>Neuromuscular Domain: FRR ES</td>
<td>0.16</td>
<td>4.18</td>
<td>.06</td>
</tr>
<tr>
<td><strong>Changes to the 12-wk time point</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Psychological domain: VAS, SF-12 MCS</td>
<td>0.08</td>
<td>1.73</td>
<td>.21</td>
</tr>
<tr>
<td>Neuromuscular domain: FRR ES</td>
<td>0.38</td>
<td>11.36</td>
<td>.004</td>
</tr>
<tr>
<td>Physical domain: fatigue ES</td>
<td>−0.06</td>
<td>0.0002</td>
<td>.99</td>
</tr>
</tbody>
</table>

The dependent variable in the regression model is the change in Oswestry Disability Index from baseline to each time point. ES, erector spinae.
VAS significantly improved from baseline to 8 weeks, but there was no further improvements after 8 weeks to the 3-month follow-up. Self-perception of physical well-being (SF-12) also improved to the highest score by the 8-week point. Self-perception of mental well-being (SF-12) was significantly improved by the 12-week time point of the study. This may be because the individuals were aware this was the end of the study and were in a more positive frame of mind about their accomplishments over the 12-week period. Although the improvements in pain and well-being perceptions mirrored the improvements in self-reported functional capacity, the regression model indicated that the changes in these psychological variables did not explain the improvements made in the Oswestry scores.

There was no significant change over time in the self-efficacy for exercise scores. The scores at baseline were high and reflect that the volunteers for this study already had high confidence in their ability to perform exercise. This is a distinguishing factor to this study, which is similar for all training studies that recruit volunteers; the participants have volunteered to participate in an exercise study so they already have a positive attitude toward exercise. It may be possible that a group of individuals with LBP, who have low self-efficacy scores, will respond very differently to the subjects in this study. This means that the results of this study should not be generalized to all patients with LBP because individuals with a negative attitude to exercise may not respond to the intervention the same way.

**Physical Changes During the Intervention**

The physical parameter that improved was the rate of fatigability, as measured by median frequency compression. This was significantly improved by the 12-week point of the study. Studies have shown that this measure of lumbar fatigue improves with physical intervention.\(^3\)\(^,\)\(^4\)\(^,\)\(^7\)\(^,\)\(^47\)\(^,\)\(^48\) There was no change in lumbar endurance, as measured by the Sorensen endurance test. This may be due to a higher baseline endurance score reported for the subjects of this study, in comparison with previous research that reported a change.\(^3\) It may be suggested that the rate of myoelectric lumbar fatigue should be included in the neuromuscular profile as the spectral analysis of the EMG signal is a reflection of the power distribution from the motor units recruited during the contraction.\(^49\)\(^,\)\(^50\) However, the changes in median frequency of the power spectrum are associated with physical manifestations of fatigue that lead to a decrease in motor unit conduction velocity.\(^51\)\(^-\)\(^53\) Although this physical assessment of fatigue improved over the 12-week intervention, the regression analysis indicates that this improvement was not associated with improvements in self-reported functional capacity.

The modified sit-up test was not an effective measure for physical capacity in this study. There was no significant change in this measurement during the study, with most subjects reaching the maximum level for this test at baseline. Isokinetic or isometric dynamometry may be a more appropriate method to evaluate the endurance capacity of the abdominal muscles in LBP subjects.

There were also no changes in the anthropometric measurements made. Sufficient change in these measures can only be made if an aerobic component was added to the program as well as nutritional advice. However, it was not a purpose of this study to combine multiple types of training intervention but to determine specifically whether the Swiss ball has any therapeutic potential because this device has received little scientific testing despite widespread use in the gym environment.

**Neuromuscular Changes During the Intervention**

A recent study found that the FR response could change with a treatment program.\(^20\) The current study has found that increases in the FRR best explained the changes measured by the Oswestry Disability Index. Specifically, by the 12-week point, the change in erector spinae FRR explained 38% of the variance in the change in Oswestry Disability Index score. The use of the FRR is in contrast to the previously mentioned study, which only categorized whether a patient exhibited FR.\(^20\) The FRR provides quantification of this phenomenon for the tracking of progression over time and for comparison between different types of treatment. This study found that the improvements in FRR were progressively made during the intervention period. The improvements in the erector spinae FRR reached their maximum by the 8-week point and did not significantly change by the 12-week point. Upon cessation of the specific exercise intervention period the FRR decreased. This is the first study to quantify a worsening in the FR phenomenon, defined by the decrease in the FRR, after the treatment period.

Silvonen et al\(^54\) reports that an absence of FR was more commonly observed in patients with current pain than those who are pain-free at the time of testing. This indicates that the absence of FR is related to the level of pain and associated guarding of the damaged region. The pattern from this study shows that the improvement trend in FR was similar to the improvement in pain intensity. Pain intensity was significantly improved by 8 weeks but did not change throughout the rest of the intervention period up to the 3-month follow-up. Flexion-relaxation had improved by the 8-week point but did not improve further by 12 weeks. There was a significant decrease in the FRR from 12 weeks to 3 months, with the values at the 3-month follow-up not being significantly different from baseline. These results suggest that improvements in FR are not dependent on improvements in perception of pain intensity, as this perception remained decreased but the FRR worsened to a level similar to baseline.

This is the first study we know of that has evaluated the changes in the latency responses of the abdominal muscles...
with an exercise rehabilitation program. No significant change in the latency response of the abdominal muscles was found, although it was shown that the patients in this study had delayed activation of the deep abdominals during the shoulder flexion task. The inability to show changes in the latency response of the abdominal muscles may suggest a lack of sensitivity of the surface electromyography technique used in this study. Most of the research into the activation of the deep abdominal and lumbar muscles during rapid limb movement has used fine-wire EMG techniques. Although the surface technique used in this study has been shown to be valid and reliable for replicating patterns of altered motor control, it may not be sensitive enough to detect specific changes in the recruitment of the transversus abdominis muscle that are suggested to occur with rehabilitation. It is also possible that the Swiss ball training simply does not influence this particular measure in a chronic LBP group. It has been previously shown that the activity of rectus abdominis is increased with Swiss ball exercises, which is in contrast to the currently advocated stabilization treatment for LBP rehabilitation, where rectus abdominis activity is minimized. The optimal training program for low back rehabilitation, especially for the motor control deficits associated with stability, has not been clearly shown. It is interesting that despite the lack of change in the feedforward measure, the participants improved significantly on several variables such as the Oswestry, pain scale, erector spinae fatigability, and feedforward activation.

The lack of a control or comparative exercise group means that no conclusion can be made about whether Swiss ball exercises are a more effective mode of training than other alternatives. This was a pilot study to show that the Swiss ball could be successfully used in a training regimen and to show that a multidisciplinary assessment protocol can provide detailed information to explain the changes that occur with a training intervention in this subgroup of patients with LBP.

**Conclusion**

This pilot study showed that the use of the Swiss ball as the mode of exercise rehabilitation may successfully improve the functional capacity of patients with chronic nonspecific LBP. Comparison with different training modalities should be performed to determine if there is one mode of exercise that is more successful than another for the rehabilitation of patients with LBP. Future studies should also investigate whether the progressive implementation of different training modalities with a greater whole body focus would lead to more positive long-term outcomes. This study used a unique model of assessment to evaluate what best explains the improvements in disability and found that the improvement in the FRR for the erector spinae best explained the improvements in disability. This provides fertile ground for future research; the use of neuromuscular measures can be used in future exercise studies to tease apart improvements related to the specificity of physical interventions such as exercise, spinal manipulation, and manual therapy, from the more global improvements in psychological health and well-being that are found in generalized multidisciplinary programs.

**Acknowledgment**

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**References**

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