Appendix: MOTOR CONTROL TRAINING INTERVENTION MANUAL

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Adapted from

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Richardson, C. A., Hodges, P. W., & Hides, J. A. (2004) Therapeutic exercise for lumbopelvic stabilization: A motor control approach for the treatment and prevention of low back pain. Churchill Livingstone, Edinburgh, UK.

Note: The information from this appendix should be supplemented by the two references above.

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Aims of motor control exercises

The goal of rehabilitation of motor control is to restore optimal control of the spine to meet the demands of each of the functional requirements of the spine. This is not equivalent to teaching a patient to maximise stability. Instead the patient is trained to match task demands with appropriate finesse to ensure that stability is maintained and that movement is allowed as necessary for the task. Rehabilitation of motor control of the spine is dependent on careful assessment of movement patterns and muscle recruitment strategies. Due to the redundancy of the motor system there is immense potential for variation in the motor control strategy adopted in individuals with low back and pelvic pain. In addition there are a large range of factors that can present as barriers to rehabilitation of control. For instance issues such as breathing pattern and posture may be associated with the patterns of adaptation in the muscle system. These factors must be assessed and managed as appropriate.

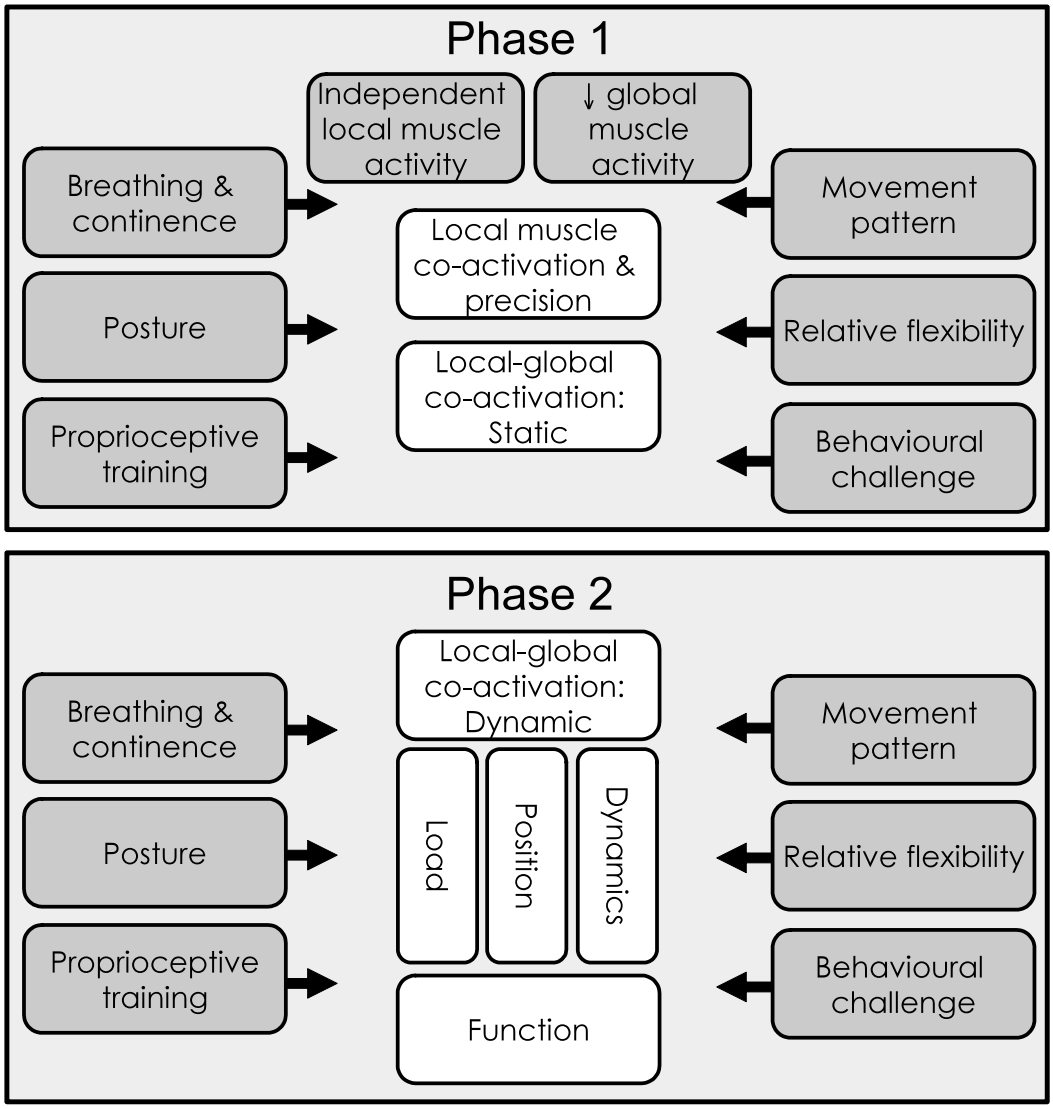
Specifically the program aims to:

1. Retrain the motor skill of the deep muscles of the spine, specifically transversus abdominus (TA), multifidus (MF) and the pelvic floor muscles (PFM).
2. Restore control of the more superficial trunk muscles
3. Encourage postures and patterns of movement that reduce pain
4. Promote early and tonic activity of the deep muscles.
5. Train coordination of the deep and superficial muscles during static and dynamic tasks
6. Train coordination of breathing and continence with trunk control strategies
7. Progress training to function

The motor control program – progression of exercise

Motor control training involves a series of progressions from initial identification and training of the motor patterns to functional retraining. The patient is progressed through the phases indicated in the middle column of Figure 1. To the sides of this column are issues that should be considered throughout the progression of exercise. The basic

treatment process involves initial identification and correction of deficits in control of the trunk muscles, both deep and superficial, through to training of coordination of the trunk muscles in function. The key to successful training is the accurate evaluation of the individual patient's strategies and the targeting of the intervention to the functional demands and limitations of the patient.



Rehabilitation of dynamic motor control of the spine and pelvis is guided by the assessment. At the completion of the assessment the therapist must have a clear picture of whether motor control is altered in the patient and which components of the system are problematic. The intervention is specifically targeted to the presentation of the patient.

Phase 1: Identification and correction of muscle activation strategies and movement patterns

The goal of this phase is to evaluate the muscle activation strategies and movement patterns, and then based on the findings of the assessment, to change/correct any aspects of muscle activation and movement that are inappropriate or provocative.

1.1 Assessment

1.1.1 Subjective assessment

The subjective assessment is similar to that normally used for assessment of a patient with back pain. Specific attention should be paid to identification of functions that are problematic and identification of functions that the patient would like to regain as a result of treatment. This is necessary to guide the development of an appropriate plan for progression of exercise. Specific attention to tasks, movements and postures that increase and decrease symptoms will aid in identification of movement patterns and postures.

1.1.2 Assessment of muscle activation patterns

Tables 2-4 provide detail of the process for *assessment of muscle activation*. Although it would be ideal to assess activation of the trunk muscles during a functional activity, this is difficult due to the location of the deep muscles and their inaccessibility to simple methods of assessment. Instead the assessment of muscle activation strategy involves assessment of the ability to perform the skill of activation of the deep muscles without the superficial muscles. The associated activation of superficial muscles provides an indication of the strategy of overactivity of the superficial muscles.

The key factor assessed is the precision of the independent activation. This is interpreted in terms of: “Which muscles are being recruited”, “what is the sequence” and “what is the quality”. Ideal performance would involve evidence of activity of the deep muscles, minimal activation of the superficial muscles and smooth slow contraction with normal

breathing. Assessment of voluntary independent activation involves teaching a patient to activate the muscle, then a range of assessment techniques are used to evaluate evidence that contraction of the deep muscles is present and evidence of substitution of the more superficial muscles. The quality and symmetry of contraction are also recorded. The typical substitution strategy is identified and recorded as this will guide management. In practice the contraction is taught, the patient is allowed several repetitions to optimise the performance of the contraction and then the assessment is performed. The goal is to hold the contraction for 10 s and repeat the contraction 10 times. The performance can be graded as outlined in Table 1. Palpation techniques for the assessment of activation of TrA and MF are presented in Fig. 2 and 3. It is ideal to perform the contractions in a number of positions to assess the range of substitution strategies that may be adopted by the patient. Assessment of the function of the pelvic floor muscles can be supplemented with additional questions to ascertain the quality of control and dysfunction of the pelvic floor (Table 5).

Table 1 Clinical rating scale of quality of contraction of deep muscles

Criteria	Score
Quality of contraction	
No contraction	0
Rapid superficial contraction	1
Just perceptible contraction	2
Gentle slow contraction	3
Substitution	
Resting substitution	0
Moderate to strong substitution	1
Subtle perceptible substitution	2
No substitution	3
Symmetry	
Unilateral contraction	0
Bilateral but asymmetrical contraction	1
Symmetrical contraction	2
Breathing	
Inability or difficulty with breathing during contraction	0
Able to hold contraction while maintaining breathing	1
Holding	

Hold <10 seconds	0
Hold >=10 seconds	1

Table 2 Assessment of the ability to activate transversus abdominis and substitution by the superficial trunk muscles

Cues	"Relaxed breath in and out, don't breath in, slowly and gently draw in lower abdomen, hold the contraction and breath, then relax slowly" "Slowly draw in the lower abdomen away from the elastic of your pants" "Slowly pull your navel up and in towards your back bone" "Slowly pull in your abdomen to gently flatten your stomach below your navel" "Slowly move my fingers together (fingers placed medial to iliac spines)"
Ideal response	Slow gentle increase in tension under fingers (see below) No/little activity of superficial muscles Smooth and Sustained (not jerky) Symmetrical contraction Approximately 10-15% effort Breathe normally 10 x 10 s contractions
Confirmation of activity	**Palpation:** Fingers placed slightly inferior and medially to the anterior superior iliac spine. Gentle but firm pressure into the muscle. During contraction of TrA there should be gentle and deep increase in tension under the fingers. With activation of OI there will be a swelling of muscle directly below the fingers. This technique is based on the anatomy of the distal region of the abdominal muscles. Muscle fibres of OE do not extend below the ASIS, OI muscle fibres are superficial and the bulk is large, TrA muscle fibres are short and deep but attach to the extensive anterior fascia. Thumbs or fingers can be used to palpate the contraction. It is ideal to assess the contraction bilaterally to assess for asymmetry. Contraction should be assessed in multiple postures. **Ultrasound imaging:** Ultrasound transducer (5-7 MHz curved or linear transducer) is placed mid-way between the iliac crest and the rib cage, transversely across the abdomen. The medial edge of the transducer is positioned such that the medial edge of the muscle is visible in the image. During contraction the TrA muscle should slide laterally (i.e. shorten relative to the overlying oblique abdominal muscles) and thicken. There should be minimal change in thickness of the adjacent muscles. **Observation:** Gentle flattening or inward movement of the lower abdominal wall may be observed during contraction of TrA.
Assessment of substitution by superficial trunk muscles	**Palpation:** Contraction of OE can be palpated in the antero-lateral aspect of the abdominal wall where it is identifiable as an almost vertical band of muscle from the ribs to the pelvis. It can also be palpated at its origin on the lower ribs. Furthermore, if the hands are placed on the lateral aspect of the abdomen contraction of OE is palpated as a broadening of the waist. OI is best palpated as bulging in the lower abdominal wall as described above. RA activity is palpated as tensing of the muscle above and below the navel. In some cases long erector spinae activity occurs to counteract the flexion moment generated by contraction of the flexing abdominal muscles. **Ultrasound imaging:** Although OE contraction is often not apparent with ultrasound imaging (possibly due to the stiffness of the tendon), OI contraction can be observed as thickening of the muscle. **Observation:** Contraction of RA/OE/OI can be observed as movement of the pelvis (posterior pelvic tilt), flexion of the thoracolumbar junction, flattening of the lower rib cage, inward movement of the upper abdomen, activation during breathing, or an inability to relax the abdominal wall. Inappropriate inward movement of the abdominal wall may also be induced by taking a deep breath and sucking in the abdominal wall. **Surface electromyography:** Surface EMG electrodes can be placed on the abdominal wall to record activity of RA and OE. For OE an ideal placement is over the distal edge of the 9th rib and on the abdominal wall just inferior and medial to this on an angle of ~45 deg. For RA the electrodes can be placed in a vertical direction ~ 2-4 cm lateral to the midline above or below the navel. Although electrodes can be placed over OI medial and inferior to the ASIS at an angle of ~20deg to the horizontal, this electrode will also record activity from TrA.

Table 3 Assessment of the ability to activate lumbar multifidus and substitution by the superficial trunk muscles

Cues	"Relaxed breath in and out, don't breath in, slowly and gently swell the muscle into my fingers, hold the contraction and breath, then relax slowly" "Think about tilting the pelvis but without really doing it" "Tense a cable running from the front of the pelvis to the spine"
Ideal response	Slow gentle increase in tension under fingers No/little activity of superficial muscles Smooth and Sustained (not jerky) Approximately 10-15% effort Symmetrical contraction Breathe normally 10 x 10 s contractions
Confirmation of activity	**Palpation:** Activity can be palpated as a slow gentle increase in tension under the fingers. Palpation techniques can involve the tip of a thumb and the mid phalanx of the index finger, two thumbs, or a thumb and the finger pad of the index or middle finger. Although two thumbs can be ideal for assessment of symmetry, it can be beneficial to use a single hand technique so that the other hand can be free to palpate other muscles. During contraction of MF, activity of TrA is also commonly palpated in the anterior abdominal wall. **Ultrasound imaging:** Contraction of MF can be best observed with the ultrasound transducer placed parasagittaly ~2-3 cm lateral to the mid line. In this image the facet joints are observable as "humps" and the muscle between the tops of the facet joints and the fascia/skin at the top of the image is the multifidus muscle. During contraction there should be movement of the fascicles of the muscle and an increase in the thickness of the muscle. Emphasis in placed on slow gentle increase in thickness, particularly on the deep fibres in the muscle. **Observation:** During contraction of MF there is minimal observed movement although the fingers that are used to palpate the muscle can often be observed to be pushed away by the contracting muscle.
Assessment of substitution by superficial trunk muscles	**Palpation:** Contraction of the long erector spinal muscles can be palpated, particularly lateral to the multifidus and at the thoracolumbar junction. Contraction of the superficial abdominal muscles suggests bracing. **Ultrasound imaging:** Contraction of the superficial muscles is often identified by rapid contraction on ultrasound imaging. Contraction of the long erector spinae is obvious from palpation or surface EMG and ultrasound imaging is not required. **Observation:** Contraction of the superficial paraspinal muscles is often accompanied by anterior tilt of the pelvis and subtle extension of the thoracolumbar junction. Posterior tilt of the pelvis can sometimes be observed as an attempt to push the spine up into the fingers in the multifidus muscle. **Surface electromyography:** Surface EMG electrodes can be placed on the thoracic erector spinae and superficial abdominal muscles as described above to assess substitution.

Table 4 Assessment of the ability to activate the pelvic floor muscles and substitution by the superficial trunk muscles

Cues	"Gently tense the pelvic floor muscles as if stopping the flow of urine" "Gently lift the testes" or "Gently shorten the penis" "Gently lift the pelvic floor" "Gently pull the tail bone towards the front" "Gently pull the ischial tuberosities together"
Ideal response	Slow gentle contraction (self palpation, ultrasound imaging) No/little activity of superficial abdominal muscles Smooth and Sustained (not jerky) Approximately 10-15% effort Breathe normally 10 x 10 s contractions
Confirmation of activity	**Palpation:** Contraction of the pelvic floor muscles can be self-palpated as a lift of the perineum with the hand placed under the perineal body. With specialist training physiotherapists can manually palpated the quality, quantity and symmetry of contraction with fingers placed in the vagina or anus. **Ultrasound imaging:** Contraction of the pelvic floor muscles can be observed non-invasively with a transducer placed suprapubically and directed in an inferioposterior direction to visualise the bladder. During contraction the pelvic floor muscle will be observed to lift slowly and gently. With the transducer placed transversely the muscles on the right and left can be observed simultaneously and the symmetry of the contraction observed. With the transducer placed sagittally the anteroposterior aspect can be observed. An alternative approach involves perineal placement of the transducer to image the pelvic floor muscles transperineally. This imaging technique has the advantage that the symphysis pubis forms a bony landmark for reference during the contraction, making objective measurement possible. This technique requires specialised training. During contraction of the PFM activity of TrA is expected and can be observed with US imaging. **Surface electromyography:** Specialised surface EMG electrodes can be placed in the anus or vagina to record the activity of the pelvic floor muscles. Although there may be cross talk from adjacent hip and trunk muscles may contribute to the signal during strong contractions, this is unlikely to be the case during gentle contractions.
Assessment of substitution by superficial trunk muscles	**Palpation:** Palpable contraction of the superficial abdominal muscles suggests bracing. Patients can palpate the elevation of their own pelvic floor by placing a hand over the perineum on the perineal body. **Ultrasound imaging:** Inappropriate activity of the superficial abdominal muscles will often cause descent of the pelvic floor muscles which is observed as downward movement on ultrasound imaging. One caution with this technique is that bracing can push the transducer away and appear as if the pelvic floor muscles are descending. **Observation:** Activity of the superficial abdominal muscles can be observed as described above. **Surface electromyography:** Inappropriate bracing can also be assessed with surface EMG electrodes placed over the OE and RA as described above.

Table 5 Subjective questioning* for pelvic floor control.

Question	Interpretation
"Can you slow/stop the flow of urine midstream?"	Provides information about the ability to contract the PFM. Note: patients should not practice this regularly or during the first void in the morning as these issues may be associated with development of voiding difficulties and urinary tract infection
"Do you have difficulty initiating urination?"	May suggest increased activity of the PFM
"Do you have any symptoms of incontinence?"	Provides indication that dysfunction of the PFM may be present
"Is you incontinence associated with leakage of urine during exertion or coughing?"	Could suggest stress urinary incontinence
"Is you incontinence associated with sensations of urge to urinate?"	Could suggest urge incontinence.

* These questions provide a general view of PFM function. More sophisticated and invasive evaluation is required to confirm the findings. If the response to these questions suggests abnormal function it may be necessary to refer the patient for specialist evaluation.

1.1.3 Assessment global/superficial muscle activity

Assessment of the activity of the global/superficial muscles involves a number of components including evaluation of superficial muscle activity during assessment of activation of the deep muscles, assessment of breathing, and assessment of posture and movement pattern. Additional movement tests can be performed to assess for specific directions of force that induce either poor control or overactivity.

Initial information of whether the patient has overactivity of any of the superficial muscles and the strategy of overactivity is derived from the identification of increased activity or difficulty relaxing the superficial muscles during the test of voluntary independent activation of the deep muscles. The muscles, the quality of contraction, the symmetry and the ability to relax the muscles are recorded. During assessment of breathing an inability to relax and modulation of activity are recorded. Both breathing and voluntary activation of the deep muscles are undertaken in a variety of positions to undertaken to facilitate identification of strategies of increased activity. Activity of the superficial muscles is also observed during static postures and during movements to identify evidence of excessive activity.

1.1.4 Assessment of posture and movement pattern

This assessment of movement patterns involves observation of postures and patterns of movement used by the patient. Posture should be observed in a range of positions and patients should be observed during a range of movements and functional tasks.

Assessment of posture involves evaluation of the spinal curves and the associated muscle activity. In general it is considered that the ideal posture in sitting and standing would involve (Fig. x):

- Neutral pelvic tilt
- Lumbar lordosis
- Thoracic kyphosis with transition at around T10-11
- Cervical lordosis
- Neutral head tilt
- Minimal frontal plane curvature
- Equal weight bearing right and left
- Minimal activity of the superficial muscles
- Gentle activity of the deep muscles
- Normal breathing pattern – even distribution of motion to abdomen, basal rib cage and upper chest

Common deviations in posture include:

- Loss of lumbar lordosis or loss of lordosis in a particular region of the lumbar spine (e.g. lower lumbar spine)
- Slumped posture with upper cervical extension
- Thoracolumbar extension
- Excessive thoracic kyphosis
- Sway back (pelvis anterior to thorax)
- Excessive activity of long erector spinae
- Excessive activity of the superficial abdominal muscles (flat upper abdomen)

Assessment should include evaluation of the start and finish of curves, depth of curves, segmental changes (e.g. segmental lordosis), pelvic position, frontal curves, right/left weight bearing, activity

of deep and superficial muscles (observation/palpation//ultrasound imaging/EMG), ability to contract deep muscles. Posture should be assessed in sitting and standing.

Assessment of movement pattern: There are two components to the assessment of movement pattern: assessment of provocative movements and assessment of typical pattern and muscle activation strategies. Basic principles of assessment of movement pattern include evaluation of:

- Provocative movements/postures (e.g. pain with early extension of the spine when returning from forward flexion.)
- Asymmetry in spine/pelvic posture, movement and range
- Protected motions
- Limb movements that cause provocative motion of the spine pelvis
- Excessive superficial muscle recruitment during movements (e.g. excessive activity of erector spinae muscles during trunk flexion)

A range of movements should be performed. This would include the range of movements that are normally assessed as part of a physical assessment as well as functional movements that have been identified by the patient as problematic and specific movements that could highlight movement deficits. Movements that are helpful include; Flexion, extension, rotation and lateral flexion, Sit to stand, Walking, movement of the lumbar spine independently of the thorax. Table 4 outlines one option for assessment of movement pattern that defines clusters of observations into “syndromes” as outlined by O’Sullivan. This can be helpful to characterise patients and guide treatment.

Table 6 Movements patterns as defined by O'Sullivan

	Definition	Provocative postures/ activities	Easing postures/ activities	Posture and movement analysis	Specific posture and movement control tests
Flexion pattern	Flexion pain and loss of segmental lordosis at the symptomatic segment. Excessive flexion strain.	Pain with flexion-related postures (e.g. slouched sitting) and functional tasks (forward bend, cycling).	Extension postures/activities where lumbar spine is lordosed (e.g. standing, sitting with a lumbar roll, walking)	- Loss of lumbar lordosis during sitting and standing - Pelvis in posterior pelvic tilt - During functional tasks - loss of lordosis at 'symptomatic level' - Forward bending - early loss of lower lumbar lordosis - Loss of lordosis during sit-to-stand, squatting and gait - Increased lordosis in the upper lumbar and lower thoracic spine	Inability to anterior rotate pelvis and extend lower lumbar spine independent from thorax during aggravating postures/ movements
Flexion/ lateral shifting pattern	Tendency to flex + laterally shift at symptomatic segment	Reaching and rotating in one direction in association with flexion postures/movements	Relief in extended or lordotic postures, stretching to the opposite side from the shift, shift correction (contra-lateral glide from pelvis)	- Similar to the flexion pattern - Loss of lumbar lordosis at affected level + lateral shift at low lumbar spine - Deviate into a lateral shift position during function - Sagittal spinal movements + lateral deviation during flexion – arc of pain 'sit to stand' - typical flexion pattern presentation + tendency towards lateral trunk shift with weight bearing on ipsilateral leg	Inability to anterior rotate pelvis and extend lower lumbar spine independent from thorax during aggravating postures/movements + lateral deviation
Active extension pattern	Tendency to hold the lumbar spine actively into extension	Extension-related postures (standing, erect sitting) and functional activities (overhead activities, fast walking, running and swimming).	Flexion postures/activities where the lumbar spine is flexed (e.g. crook lying, slouched sitting)	- Actively held segmental hyper-lordosis at the symptomatic segment during upright sitting and standing postures. - Tendency to hyper-lordose at the 'symptomatic segment' During sit to stand, squatting and forward bending - Forward bending movements have	Inability to initiate posterior pelvic during aggravating postures/ movements

		Forward bending with tendency to hold the lumbar spine into segmental hyperextension		increased hip flexion and a tendency of a late 'loss of lordosis' (beyond mid flexion range) or no curve reversal - Return from forward bended position with early hyper-lordosis at symptomatic segment	
Passive extension pattern	Tendency to passively over-extend at the symptomatic segment of the lumbar spine	Similar to the active extension pattern all extension-related postures (standing, erect sitting) and functional activities (overhead activities, fast walking, running and swimming)	Flexion postures/activities where the lumbar spine is de-lordosed (e.g. crook lying, slouched sitting)	- Tendency for patients to stand into a sway-back posture (thorax posterior to the pelvis) with a segmental hinging at the symptomatic level. - Forward bending is often pain free, but on return to neutral they tend to over-extend at the symptomatic level (hinge into extension) and sway pelvis anterior	Inability to extend the thoraco-lumbar spine above the symptomatic segment with a tendency to hinge into extension at this segment
Multi-directional pattern	Multi-directional impairment	Pain in many weight bearing postures and functional activities	Difficulty to find relieving positions during weight bearing	- May assume a flexed, extended or laterally shifted spinal posture, and may frequently have to alternate them. - Excessive segmental shifting and hinging may be observed in all directions, with associated 'jerky' movement patterns and reports of 'stabbing' pain on movement in all directions with observable lumbar erector spinae muscle spasm	Patients have great difficulty assuming neutral lordotic spinal postures, with over shooting into flexion, extension or lateral shifting postures

1.1.5 Assessment of breathing pattern

In most patients it is important to evaluate the breathing pattern in order to identify any abnormal recruitment of the trunk muscles, any features that may complicate the optimal control of the spine and pelvis (e.g. excessive superficial abdominal muscle activity, excessive abdominal movement), and any features that would indicate inefficiency in the breathing apparatus (e.g. upper chest breathing pattern). Components of the assessment are presented in Table 7.

Table 7 Techniques for assessment of breathing

Parameter	Techniques
Chest wall movements	**Principle:** Quiet breathing should involve movement of the abdomen, basal rib cage and upper chest. No region should be dominant. Basal rib cage movement will be greater in positions in which tension in the abdominal wall resists abdominal displacement and therefore causes diaphragm shortening to elevate the lower ribs **Abdomen:** Observe motion in the upper and lower abdomen. Movement should be present in each region and not confined to inward movement of the upper abdomen with OE contraction. **Basal rib cage:** Movement should be smooth and symmetrical. Hands placed on the lower rib cage can assess symmetrical movement. **Upper chest:** Upper chest movement should be observed, without excessive activity of sternocleidomastoid.
Respiratory activity of the trunk muscles	**Principle:** During quiet breathing in supported positions there should be minimal activity of the superficial abdominal muscles during expiration. Activity of TrA should be present. In unsupported positions slight activity of OE/OI and/or RA may be noted to aid elevation of the diaphragm. Diaphragm should descend smoothly during inspiration. **TrA:** Actvity can be palpated in the lower abdominal wall and sustained activity measured with ultrasound imaging. There should be slight modulation of activity with breathing, particularly in positions in which the abdomen is dependent. Activity should be sustained throughout the respiratory cycle. **OE/OI/RA:** Activity can be observed, palpated or recorded with surface EMG electrodes as described above. Some modulation of activity with respiration may be noted during breathing in unsupported positions. **Diaphragm:** Diaphragm activity can be monitored by evaluation of abdominal and bibasal rib cage motion. More specific assessment can be achieved with ultrasound imaging. Ultrasound imaging can be used to assess diaphragm displacement using a trans-abdominal approach, diaphragm thickening using a transverse approach with the transducer placed in a rib space, and diaphragm length changes can be estimated with the transducer placed longitudinally down the lateral rib cage. For the trans-abdominal approach a 3 MHz transducer is placed on the abdomen below the rib cage and the transducer is directed upwards to visualize the diaphragm which appears as a white line at the border between with the lung. The border should move caudally and cranially with breathing. For the measurement of thickening the transducer is placed in the 8/9th intercostals space and the muscle can be identified as the deepest of three muscle layers. The muscle will thicken during inspiration. The length of the diaphragm can be measured with the transducer placed longitudinally down the rib cage in the anterior axillary line. The top of the diaphragm is identified by the white shadow formed by the lung and the origin is identified inferiorly. The muscle should shorten during inspiration. **PFM:** The PFM should contract tonically in upright positions, but the activity can be modulated with breathing. With ultrasound imaging it should be possible to observe that the muscle does not descend during any respiratory phase. With surface EMG the muscle activity may be modulated with breathing.

1.2 Training

Rehabilitation of dynamic motor control of the spine and pelvis is guided by the assessment. At the completion of the assessment it is essential to have a clear picture of whether motor control is altered in the patient and which components of the system are problematic. The intervention is specifically targeted to the presentation of the patient.

Rehabilitation involves a motor learning approach. Motor learning involves the acquisition and refinement of movement and coordination that leads to a permanent change in movement performance. This can be achieved by drawing on the principles of motor training for skill learning. Different researchers have defined either two or three phases of motor learning. Fitts and Posner (1967) proposed three phases. The *Cognitive phase* focuses on cognitively based problems and all components of the task are organised cognitively with attention to feedback, movement sequence, and quality of performance. The *Associative phase* commences once the patient has acquired the fundamentals of the movement and the focus shifts to emphasise the consistency of performance and the cognitive demands are reduced. In the *Automatic phase*, which is achieved after considerable practice, the demand for conscious intervention is reduced and the focus shift to transferring the task between environments. Gentile (1987) proposes two phases, which parallel those of Fits and Posner. In phase one the patient "gets the idea" and in phase two the emphasis is on fixation and diversification of the skill.

Motor learning provides principles for optimal training of motor function. Motor learning of complex movements can be facilitated by practice of parts of the movement (i.e. segmentation) before practicing the whole movement. Learning can be facilitated by simplification of the task by reduction of load, for instance, to make it easier for the patient to perform the task correctly. Feedback is critical to ensure learning. Feedback of both the quality of performances and the results of the task can be provided.

Training of motor control of the trunk in the framework of motor learning involves training of the components of function that were found to be problematic in the assessment.

1.2.1 Activation of the deep muscles of the spine and pelvis and reduction of overactivity of the superficial muscles

In many patients assessment will have identified poor activation of some component(s) of the deep muscle system and evidence of over-activity of one or more of the superficial muscles. Table 8 presents a range of strategies to deal with these issues. At the completion of the initial session it is critical to be able to answer three questions. (1) What strategy worked best for the patient? (2) How can you be sure that the patient will practice the correct task at home (e.g. strategies for feedback of contraction of the deep and superficial muscles)? (3) What will the home program be (i.e. the number of contractions and the duration of hold up to 10 x 10 s contractions [best identified via repeated contraction once a strategy has been identified])?

Exercise is progressed by increased number of repetitions, increase holding time, reduction of feedback (gradual weaning) and progression to perform contractions in different positions.

1.2.2 Rehabilitation of breathing pattern

It is essential that patients can breath effectively at all levels of training. In the initial phases of training, breathing can be used as a strategy to aid patients to learn effective control strategies. Later in training the emphasis shifts to ensuring that progression of exercise does not compromise ability to coordinate breathing, stability and movement. As described earlier for assessment optimal breathing involves movement of the abdominal wall, basal regions of the rib cage, and some movement of the upper chest. Table 9 presents a range if issues of breathing control that must be assessed along with strategies for management.

Exercise is progressed by weaning from techniques to change breathing, to train in different positions, and to incorporate into functional tasks.

1.2.3 Rehabilitation of Functional posture: Movement patterns and posture

Postural correction has a number of aims:

- To optimise posture
- To avoid provocative postures
- To optimise loading
- To reduce overactivity of superficial/global muscle activity
- To aid activate deep/local muscles in functional postures
- To assist with optimisation of the respiratory pattern

- To aid in the optimisation of control of pelvic floor muscles

However, there are a number of factors to consider. First, although the ideal neutral posture has been argued to involve neutral pelvic tilt, lumbar lordosis, smooth transition to thoracic kyphosis, and cervical lordosis, it is important to consider that this may not be ideal for all patients. For instance, specific pathologies require consideration (e.g. spinal stenosis is likely to require less extension in the lumbar spine). Second, there must be sufficient range of motion to achieve the posture. This should be assessed by palpation of interspinous motion during movement. Manual techniques may be appropriate to aid development of range. Third, it is critical that the position is comfortable and can be maintained with minimal activity of the large superficial muscles. It is reasonable for the position to feel awkward. If there is pain or of the position is difficult to hold then the position must be modified within this constraint. A final consideration is that the purpose of training postural control is not to encourage the patient to hold this position statically, but to move into and out of the posture as required by a task. A key factor is that the spine is flexible and not rigidly held in the position such that movement can be used to contribute to control as required. Encouragement to control posture when sitting or standing for extended periods is ideal to avoid creep.

A range of techniques are available to correct posture. The techniques used are dependent on the findings of the assessment. Key areas that often require control are the thoracolumbar junction and lumbar lordosis. Table 10 presents a range of factors that require consideration and strategies that can be used for training. It is often easiest to start in sitting with the hips flexed to ~60° to allow free movement of the pelvis. Postural correction can be undertaken by practice of components prior to practice of the complete manoeuvre in subsequent sessions. Once posture is corrected, activation of the deep muscles should be attempted to encourage functional integration of the manoeuvre.

Table 8: Clinical strategies to increase activity of deep muscles and decrease activity of global/superficial muscles

Goal	Clinical strategies
Techniques to decrease activity of superficial muscles	**Posture:** • Supported postures may aid in the reduction of activity of global muscles. Supine crook lying, side lying and prone over a pillow (to relax the paraspinal muscles) may be helpful. • Appropriate support with pillows and consideration of position of the arms and legs. • Specific attention to the spinal curvature (even in supine), to place a patient in a more neutral position may assist in the reduction of superficial activity. • Consider provocative movements. Correction of these may aid relaxation. **Breathing:** • If tonic activity persists or if activity of the superficial muscles is modulated with breathing it may be helpful to encourage relaxation by re-education of breathing. • Focus on active inspiration using diaphragm contraction (movement of the abdominal wall and basal rib cage) and relaxed expiration. • Manual contact to encourage basal rib cage expansion. • EMG biofeedback of expiratory activity. **Effort:** • Patients may require encouragement to reduce their effort such that they stop at a level below that at which the superficial muscles become active. **Feedback:** • Feedback of contraction of the superficial muscles can be used to provide greater awareness of activation. Many options are available: palpation, observation in a mirror, surface EMG biofeedback. **Imagery:** • Using images can help a patient “get the idea”. Examples may include thinking of the sand building up in an hourglass to give the “idea” of the slowness required
Techniques to increase activity of TrA	**Instruction:** • Careful instruction is critical to ensure that subjects are clear that the task is not aimed at strength, but the emphasis is control • Emphasis is placed on slow and gentle **Position:** • Positions which allow some stretch on the muscle can improve the sensation of movement of the abdominal wall. However, if a supported position is required to reduce the overactivity of the superficial muscles that takes priority. • Side lying can provide a balance between support and stretch on the muscle **Co-activation:** • Activation of the PF muscles or multifidus initiates activity in TrA • Contractions of the PF must be performed in a slow and controlled manner. Activation is best if the focus is the anterior pelvic floor and the spine is in neutral. Techniques for activation of the pelvic floor muscles is outlined below **Feedback:** • Techniques to enable patients to evaluate quality and quantity of contraction are ideal. • Techniques include palpation medial to the anterior superior iliac spines, observation of inward movement of the lower abdomen and US imaging

	Imagery: • Images can help learn activation of TrA, such as pulling the right and left ASIS together
Techniques to increase activity of MF	**Instruction:** • Careful instruction is critical to ensure that subjects are clear that the task is not aimed at strength, but the emphasis is control • Emphasis is placed on slow and gentle tension or swelling of the muscle **Position:** • Positioning the patient in neutral, with specific attention to ensure that that thoracolumbar junction is not held into extension by the long erector spinae is critical **Co-activation:** • Activation of the PF muscles or TrA can initiate activity in MF • Contractions of TrA and the PF must be performed in a slow and controlled manner. **Feedback:** • Techniques to enable patients to evaluate quality and quantity of contraction are ideal. • Palpation with the fingers placed over the muscle are ideal as long as the patient can comfortably reach around the back. • A small piece of tape on the skin over the muscle can assist the patient to find the correct level easily. **Imagery:** • Imagining approximation of the hip into the acetabulum can activate MF • Imagining tensioning a cable from the ASIS to the spine wit the hands placed on both of these points (Lee, personal communication) • Thinking about tilting the pelvis, without movement, can help but it must be emphasised the task is not about movement. This strategy is best avoided in people with pain provocation with extension.
Techniques to increase activity of PF	**Instruction:** • Instructions to activation the PF include: contract as if you are stopping the flow of urine, lift the sling of muscle that runs between the front of the pelvis and the tail bone, pull the ischial tuberosities together. Lifting the testes or shortening the penis can be effective for men. **Position:** • Pelvic floor muscle activity can be increased in a neutral position of the pelvis with lumbar lordosis. **Co-activation:** • Activation of the TrA or MF can initiate activity in PF • Contractions of TrA and MF must be performed in a slow and controlled manner. **Feedback:** • Self palpation of lift of the perineal body • Ultrasound imaging of lift of the bladder base using a transabdominal approach • Palpable contraction of TrA during PF activity may provide an indirect form of feedback

Table 9 Interpretation of assessment and strategies to encourage efficient breathing pattern

Problem	Interpretation	Management
Limited basal expansion of rib cage	Increased activity of OE/RA/OI preventing rib elevation	Techniques to decrease OE/RA/OI activity – e.g. feedback (EMG, palpation) Encourage controlled breathing with active inspiration and relaxed expiration Techniques to encourage basal expansion – manual feedback, elastic strap around thorax to enhance awareness
	Stiff/hypomobile thoracic spine and rib cage	If basal expansion is restricted by poor flexibility of the rib cage this may be managed with manual techniques and mobility exercises
	Hyperinflation of the thorax	This is generally related to respiratory disease. Maybe difficult to change, but may be helped by attempts to improved respiratory efficiency
	Reduced potential of the diaphragm to shorten	May be restricted by fixation of the rib cage and increased IAP by abdominal muscle activity (use techniques as above to encourage diaphragm breathing) May be related to primary diaphragm issue. Train motion of rib cage
Excessive abdominal displacement	May compromise the ability to maintain the tonic contraction of TrA. TrA should be tonic, but modulated with breathing	Encourage basal expansion – as above
Excessive upper chest movement	Increased activity of OE/RA/OI preventing rib elevation and displacement of the abdominal wall	Encourage basal expansion – as above
Inability to maintain contraction of deep muscles during breathing	Inability to hold due to demand to use abdominal wall movement for breathing	Encourage basal expansion – as above
	Inability to maintain contraction during inspiration	Enhance feedback of contraction with palpation, observation (US). Inspiratory volume training – gradually increase inspiratory volume during successive breaths until the threshold is identified.
	Shifts breathing pattern to shallow or upper chest breathing	Encourage basal expansion – as above. Inspiratory volume training – gradually increase inspiratory volume during successive breaths until the threshold is identified.
	Poor posture that prevents normal motion of rib cage with breathing with increased demand on abdominal wall movement. Rotated positions increase demand for abdominal wall displacement	Postural correction to reduce rotation and encourage normal basal expansion of the rib cage – neutral spinal posture

Rehabilitation of *Movement patterns* can be assisted by categorisation of patients based on movement patterns provides guidance regarding the requirements for control of provocative postures and movements, correction of movement faults and consideration of adjacent joints. Findings of the assessment of movement patterns will have provided essential information regrading the provocative movements and relieving postures. This also provides some guidance regarding the components of the muscle system that must be trained. Treatment is directed at training muscles, movements and postures that control the provocative movements/postures. For instance, for a patient presenting with a flexion pattern the program would include training for the paraspinal muscles (particularly the superficial regions of multifidus), training movement at the hip to reduce dependence on spinal flexion, and correction of posture (particularly control of the lumbar lordosis in standing and sitting).

Progression of exercise involves increased speed and complexity of movement, progression from sitting to standing, progression from static control of postures to dynamic control of posture and movement during function. Initial stages of posture and movement pattern correction may be achieved with practice of components of the task, e.g. dissociation of pelvic movement from movement at the thoracolumbar junction. Progression may involve incorporation of an increasing number of components and increased duration of holding.

Table 10 Techniques for postural correction

Factor to be addressed	**Cues and techniques**
Forward or backward leaning	**Feedback:** Hands placed on manubrium should be immediately over a hand placed on the anterior aspect of the pelvis.
Uneven weight bearing through ischial tuberosities	**Feedback:** Hands placed under the ischial tuberosities can be used to provide feedback of symmetry of weight beaing
Excessive thoracolumbar extension	**Manual handling:** With the therapists hand placed on the sternum and thoracolumbar junction the patient is encouraged to sink to flatten the TL junction. The patient can be allowed to temporarily roll on the pelvis, but should not simply slump. **Feedback:** With the thumb of one hand on the xiphoid and the little finger of the same hand in the navel can be used as this distance reduces with thoracolumbar flexion. **Cues:** “Let your chest sink” “Open at the back” “Inspire/breathe into the mid back”

	Avoid: Care not to use scapula protraction to simulate thoracic movement. Avoid slump of upper thorax and take care to correct the head position by nodding forward (i.e. avoid upper cervical extension)
Decreased lumbar lordosis or flexion (often in low lumbar spine)	**Manual handling:** Hand placed on the superior aspect of the sacrum or the flexed segments can be used to provide gentle encouragement to move the spine. If the patient has difficulty dissociating lumbar and thoracic motion, an intermediate step could be to have the patient rock the pelvis without motion of the thorax in a four-point kneeling position. **Feedback:** With the thumb of one hand on the xiphoid and the little finger of the same hand in the navel can be used to monitor and avoid thoracolumbar extension. **Cues:** "Imagine a string attached to your tailbone, and some is gently pulling the string up to the sky" "grow tall from the tailbone" "allow the ball to roll underneath you, and let the pelvis fall forward" "Roll forwards on your tailbone" **Avoid:** Avoid strong activation of the paraspinal muscles, task should be able to be completed with gentle activity of the lumbar muscles, particularly the superficial fibres of multifidus. Avoid extension at the thoracolumbar junction. May require feedback of motion at this segment with hand placed on the xiphoid and navel. This distance should not change during motion.
Increased thoracic kyphosis	**Manual handling:** Hands can be used to provide a sensation of lengthening by spreading 2 fingers along spinous processes over the segments to be flattened. **Cues:** "Imagine a spot on the top of your head being gently pulled up to the sky" **Avoid:** Avoid motion simply by extension at the thoracolumbar junction.

1.2.4 Relative flexibility

If there is restriction of motion of the adjacent joints this needs to be rectified in order for the spine to have normal function. Evaluation of movement patterns will provide an initial indication of the importance of function of the adjacent joints.

1.2.5 Co-activation of deep muscles and improved precision of training

An initial goal is to encourage co-activation of the muscles of the deep system. As indicated above, activity of the deep muscles often occurs together and this can be used as a method to initiate contraction of the other deep muscles. However, it is important to assess the degree of co-activation that has been achieved and whether specific intervention is required to encourage this. Patients generally fall into one of three categories; those who have automatic co-activation of the deep muscles, those who require emphasis placed on the other muscles (e.g. feedback of other

muscles of the system), and those who require separate exercises for each muscle to be integrated later. The other goal of this step of the intervention is to improve the precision and efficiency of the control of the deep muscle system. This involves increased holding time, increased number of contractions, reduced feedback (i.e. gradual weaning from feedback) and decrease reliance on special techniques involving position and co-contraction. At the completion of this phase the goal is for the patient to have achieved confident activation of the deep muscles. This means that the contraction should be independent of the superficial muscles (but the deep muscles all working together), the contraction should be able to be performed voluntarily, with minimal feedback, minimal effort, held for 10 s and the person should be able to breathe while holding the contraction. When this is achieved the patient can progress to the next phase of training.

At the completion of the initial session it is critical to be able to answer three questions:
(1) What strategy worked best for the patient to activate the deep muscles and reduce overactivity of the superficial muscles?
(2) What movement patterns or postures need to be controlled?
(3) How can you be sure that the patient will practice the correct task at home (e.g. strategies for feedback of contraction of the deep and superficial muscles)?
(4) What will the home program be (i.e. the number of contractions and the duration of hold up to 10 x 10 s contractions [best identified via repeated contraction once a strategy has been identified])?

1.3 Home daily exercises

The subject is always sent home with a set of exercises. Exercises will be encouraged to be performed daily for a total of 30 min during the first month and a total of 1 hour for the second month. These exercises should be performed at the same level, with the same facilitation technique, in the same position as those demonstrated during the treatment session. A short period of high quality training is sufficient in the early phases of training. This should be performed 3-4 times per day. Emphasis should be given to avoid fatigue and undesired contractions. It is explained to the subject how important performance of the daily exercises is for the success of the treatment. The program should include exercises for any component that requires correction and

may include exercises to reduce activity of superficial muscles, a strategy for facilitation of 1 or more of the deep muscles, and strategies for correction of posture and movement patterns.

As performance improves the patient should be encouraged to incorporate training into their function. For instance, patients should be encouraged to contract while sitting at their desk or other work activities. They should be encouraged to link training with some trigger, such as performing a contraction each time they answer the phone, etc. In this way the frequency of training can be increased.

The objectives of Phase 1 are;

Confident contraction of deep muscles

- **Independent**
- **Cognitive**
- **Minimal feedback**
- **Minimal effort**
- **10 s hold**
- **Able to maintain optimal relaxed breathing pattern**

Co-activation of deep muscles

Correct posture and movement pattern

Correction of relative flexibility

Phase 2: Progression of exercise to function

Once the initial goals of improved activation of the deep muscle, decreased overactivity of superficial muscles, rehabilitation of breathing pattern, and correction of posture and movement patterns, it is necessary to begin progression of exercise to take the patient through to functional rehabilitation. As presented in Fig. 1 this can be achieved by progression through exercises of increasing complexity, again specific to the patient's presentation, i.e. with the patient's goals for return to function.

2.1 Co-activation of deep and superficial muscles: Static

When the patient can perform confident activation of the deep muscles it is then necessary to train coordination between the deep and superficial muscle systems. The easiest was to initiate this training is with static tasks. Static control training has two key goals: training of the integration between the local and global muscles, and training the control of lumbopelvic orientation/alignment. The key to this phase is to pre-activate the deep muscles, hold this activation tonically, and then use load and resistance to initiate activity of the superficial muscles over the top. The underlying principle is that once load is applied to the limbs or trunk, activation of the global muscles is required to control the alignment. Many possibilities for training this level have been presented in the clinical literature. Table 11 presents the principles and some examples of several of the most common approaches. Many other examples are available and the basic principles are similar to those described above.

Table 11 Strategies to train static coordination between the deep and superficial muscles.

Strategy	Principles	Example exercises
Leg loading	In crook lying load is applied in a progressive manner by moving the legs in different planes of motion. The patient is instructed to maintain the position of the spine and pelvis.	Bent knee fall outs: leg is slowly lowered to the side while maintaining the position of the pelvis and spine. The position of the spine and pelvis can be monitored with a pressure biofeedback unit. Specific directions of greater and lesser control can be identified by directions of movement which are associated with loss of control of alignment.
Rhythmic stabilisations (proprioceptive neuromuscular facilitation)	The patient maintains a neutral position as force is applied to the body. Force is normally low (~30%) and the direction slowly alternates.	In sitting with neutral alignment rotary force can be applied to the shoulders in alternating directions. During the change in direction the activation of the superficial muscles alternates over the top of the tonically maintained activation of the deeper muscles
Limb loading	The neutral position of the spine is maintained in any body position as load is applied first through short levers (bent limbs) and then through longer levers with the limbs straight.	In a quadruped position the position of the spine is maintained in neutral as either and arm or a leg or both are moved to the side or in the sagittal plane. Postural preparations are required to ensure the centre of mass is placed over the new base of support.
Pilates	Load is applied though the use of limb load, springs and other equipment as the spine is maintained in a neutral position.	On a reformer bed (sliding bed with springs adjusted to resist the motion of the bed) the patient precontracts the deep muscles and maintains the neutral position as the sliding surface is translated by extension and flexion of the bed. Although this technique often involves movement on expiration, it may be more ideal to train movement with both phases of breathing.
Balls	The neutral position of the spine is maintained while the body is partly or completely supported on a ball. Load can be added by addition of limb load.	Patients can sit in neutral on a large ball with the hips above 90°. Load can be applied by reduction of the base of support (lifting a leg) or by increasing the load (by movement of the arms or legs)

Comprehensive assessment of whether superficial muscle activity is sufficient to meet the demands of control of buckling can be obtained by assessment of the control of the orientation of the spine and pelvis during simple movement tasks. One system for evaluation of control by the superficial muscles involves assessment of the control of pelvic and lumbar position during a progression of limb loads in crook lying (supine with the hips and knees flexed). The task involves instructing the patient to maintain the position of the pelvis and spine during a sequence of leg movements involving; abduction and external rotation of the leg, extension of one or both legs with and without support. Assessment involves evaluation of directions of motion that are associated with poor control of pelvic or lumbar position. This can be assessed with a pressure cuff placed under the spine to evaluate the motion of the spine and pelvis. Other models are available to assess this component of the system.

2.2 Co-activation of deep and superficial muscles: Dynamic

More complex than static control, but essential for progression to function, is the requirement to train control of the spine and pelvis in dynamic situations. Several strategies are available from tasks that involve support on an unstable surface to control during specific movements of the trunk. The key elements are to pre-activate the deep muscles and hold this tonically while movement is performed. Several examples are presented in Table 12. The tasks should be selected from those that are identified as target functions by the patient. Principles of segmentation and simplification can be used. Simple tasks such as control during range of motion tasks with emphasis on the control of posture and muscle activity during the movement.

Table 12 Strategies to train dynamic coordination between the deep and superficial muscles.

Strategy	Principles	Example exercises
Unstable surfaces	The patient aims to maintain balance and alignment of the trunk when placed on an unstable surface. In order to maintain balance movement of the spine is necessary as it is impossible to maintain balance simply by control at the ankle.	Standing on balance board, sitting on ball, balance Shoes (Janda).
Function-specific tasks	Specific movements that are required for function are trained. The movement is segmented, simplified and performed with reduced speed and reduced load.	Walking (progressing from side-side weight shift), trunk rotation.

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2.3 Progression of load, position and dynamics

Although it is critical that patients do not progress too soon, it is also critical to ensure that patients are progressed to a high enough level to meet functional demands. The functional demands of the individuals work and leisure activities must be assessed and exercise must be progressed through load, position and dynamics to meet these demands. For instance it may be necessary for a patient to work at high levels of resistance, or in unstable environments. Appropriate progression with a gym based program may be required. Specific attention should be placed on the control of the deep muscle contractions during the progression, on the specific movement and postural faults identified in the assessment, and on the ability to maintain breathing during the progressions.

2.4 Functional rehabilitation

Functional training follows similar principles to the preceding phases but focuses on the training of functional tasks. Again the principles of pre-activation of the deep muscles, with segmentation and simplification of the task are undertaken. Ideally the goal is that the activation of the deep muscles will be automatic, with minimal requirement to activate the muscles consciously. However, in is helpful to initiate training with pre-activation to ensure integration of this component. Again attention to movement and postural faults and breathing are required. Progression should include practice in more challenging environments to ensure transfer of training. Practice closer to the actual functional demands is likely to lead to better transfer.

2.5 Behavioural challenge

A final issue worthy of consideration is the requirement for behavioural training. As mentioned in section 3.7 fear of pain and/or (re)injury has the potential to disrupt the control of the trunk muscles in a similar manner to the actual experience of pain. For this reason it may be expected that although a patient may be able to maintain ideal control in the safe closed environment of a clinic, this may not be the case when moving in real-world environments. Patients may require specific training drills to maintain control while rehearsing specific contexts. This is described in detail elsewhere (Moseley &Hodges 2005).

2.6 Principles of progression

Although it is critical that patients do not progress too soon, it is also critical to ensure that patients are progressed to a high enough level to meet functional demands. The functional demands of the individuals work and leisure activities must be assessed and exercise must be progressed through loads, position and dynamics to meet these demands. Patient goals must be agreed by the patient and therapist and short and long term goals set for progression of exercise towards regaining successful function. Specific attention should be placed on the control of the deep muscle contractions during the progression, on the specific movement and postural faults identified in the assessment, and on the ability to maintain breathing during progressions.

2.7 Home daily exercises and instructions

Subjects are instructed to perform the exercises in the positions and with resources available at home. Pre-activation of the deep muscles is encouraged before any functional task such as walking, bending and carrying loads. If subjects are willing to engage or re-engage in social/sports activities they should be encouraged to do so. Continued attention to correction of posture and movement patterns is required.

Once the intervention is finished the therapist should instruct subjects to continue performing the exercises a minimum of three times a week. Instructions for maintaining the performance of the deep muscles and the risk of decreasing the stability of the spine if the exercises are not performed should be given.

The objectives of Phase 2 are;
Appropriate activation of global muscles over local muscles
Control of lumbar position during limb movement
Assess and train specific deficits in global system
Automatic activity
Appropriate control during target functional tasks

Treatment Record Sheet – Motor Control Exercises

Name: Trial #:		
SESSION	DATE	SHORT DESCRIPTION OF TREATMENT AND DURATOIN
1		
2		
3		
4		
5		
6		

SESSION	DATE	SHORT DESCRIPTION OF TREATMENT AND DURATOIN
7		
8		
9		
10		
11		
12		