Kinetic Control

Understanding Movement & Function

Course Pre-Reading

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Kinetic Control courses have developed from a gradual synthesis of a variety of different approaches and concepts, along with the ongoing development and integration of original ideas and applied principles. Kinetic Control Movement Dysfunction Courses have evolved into an evidence-based system of analysis of movement and function, assessment of movement dysfunction and retraining of functional movement and postural control. Kinetic Control courses are designed around a rehab model to manage pain and pathology within the musculoskeletal system.

A parallel development of the Kinetic Control movement dysfunction courses has led to the establishment of Performance Stability courses. The Performance Stability training and accreditation courses have evolved into a system of stability assessment, performance analysis and risk management using the ‘Performance Matrix’. It allows assessment of low and high load ‘weak links’ in the movement chain; analysis of performance deficits; and identifies potential risk of injury and performance failure. This then directs the development of client-specific performance enhancement and preventative risk management training programmes.
PHYSIOLOGICAL CONSIDERATIONS

MOTOR UNIT FUNCTION

Most muscles are composed predominantly of two different types of motor units. There are slow low threshold (tonic) motor units and fast high threshold (phasic) motor units. Research has identified other types of motor units, but this basis classification is useful for rehabilitation purposes (Lieber 2002).

<table>
<thead>
<tr>
<th>FUNCTION</th>
<th>SLOW MOTOR UNITS (tonic recruitment)</th>
<th>FAST MOTOR UNITS (phasic recruitment)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contraction Speed</td>
<td>slow</td>
<td>fast</td>
</tr>
<tr>
<td>Contraction Force</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>Recruitment Dominance</td>
<td>primarily recruited at low % of MVC (&lt; 25%)</td>
<td>increasingly recruited at higher % of MVC (40% %) or if plan to perform a fast movement</td>
</tr>
<tr>
<td>Recruitment Threshold</td>
<td>low (sensitive)</td>
<td>high (insensitive)</td>
</tr>
<tr>
<td></td>
<td>- easily activated</td>
<td>- requires higher stimulus</td>
</tr>
<tr>
<td>Fatiguability</td>
<td>fatigue resistant</td>
<td>fast fatiguing</td>
</tr>
<tr>
<td>ROLE</td>
<td>control of normal functional postures &amp; unloaded movements</td>
<td>rapid or accelerated movement &amp; high load activity</td>
</tr>
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</table>

The key points are that slow motor units have a low threshold of activation, slow speed of contraction, a low contraction force and are fatigue resistant. Fast motor units have a high threshold of activation, fast speed of contraction, a high contraction force and fatigue quickly. Research has demonstrated that slow motor units are predominately recruited during normal daily activities (Monster et al 1978).

Recruitment and hypertrophy are very different processes. Recruitment is modulated by the higher central nervous system and is powerfully influenced by the afferent proprioceptive system along with many psycho-social factors. Hypertrophy is a peripheral structural adaptation in muscle to demand along with central nervous system neural adaptation and is the result of overload training (Vander et al 1994). Hodges (2003) argues that strengthening the muscles of range and force potential and motor control training of deeper (force inefficient) muscles are two distinctly separate process, both of which are required to perform to high levels of activity such as competitive sport.

PAIN AND RECRUITMENT

There is consistent evidence of altered recruitment in the presence of pain. Pain affects slow motor unit recruitment more significantly than fast motor unit recruitment. Pain does not appear to significantly limit an athlete’s ability to generate power and speed ...so long as they can mentally “put the pain aside”. It has been suggested anecdotally that up to 90% of sporting world records are broken by athletes with a chronic or recurrent musculo-skeletal pain problem.

Recent research (Hodges & Moseley 2003) indicates that in the pain-free state, the brain and the central nervous system (CNS) are able to utilise a variety of motor control strategies to perform functional tasks and maintain control of movement, equilibrium and joint stability. However, in the pain state, the options available to the CNS appear to
become limited. These altered (or limited) motor control strategies present as consistent co-contraction patterns usually with exaggerated recruitment of the multi-joint muscles over the deeper segmental muscles.

These altered strategies or patterns have been described in the research and clinical literature as ‘substitution strategies’, ‘compensatory movements’, ‘muscle imbalance’ between inhibited / lengthened stabilisers and shortened / overactive mobilisers, ‘faulty movements’, ‘abnormal dominance of the mobiliser synergists’, ‘co-contraction rigidity’ and ‘control impairments’.

**FUNCTIONAL IMPLICATIONS OF RECRUITMENT:**

- Dynamic postural control and normal low load functional movement is primarily a function of slow motor unit (tonic) recruitment.
- Functionally, efficient recruitment of slow motor units will optimise postural holding / anti-gravity and stability function.
- Normal postural control and functional movement of the unloaded limbs and trunk should ideally demonstrate efficient recruitment of deeper, segmentally attaching muscles that provide a stability role.
- Low load training and exercise can optimise slow motor unit recruitment (not high load or overload training).
- Functionally, efficient recruitment of fast motor units will optimise rapid / accelerated movement and the production of high force or power.

- High load activity or strength training (endurance or power overload training) is a function of both slow (tonic) and fast (phasic) motor unit recruitment.
- High load or high speed activities normally demonstrate a dominance of recruitment of more superficial, multi-joint muscles that are biomechanically advantaged for high load, large range and high speed.

**LOW versus HIGH THRESHOLD**

<table>
<thead>
<tr>
<th>Activity or function that stimulates low threshold (tonic) recruitment of slow motor units (SMU) (related to low load / force and low speed)</th>
<th>Activity or function that stimulates high threshold (phasic) recruitment of fast motor units (FMU) (related to high load / force and high speed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>postural sway</td>
<td>accelerated movement</td>
</tr>
<tr>
<td>maintained postural positions</td>
<td>rapid movement</td>
</tr>
<tr>
<td>non-fatiguing movements of the unloaded limbs and trunk at a natural comfortable speed</td>
<td>large or sudden shift in the centre of gravity</td>
</tr>
<tr>
<td></td>
<td>high force or heavy loads</td>
</tr>
<tr>
<td></td>
<td>conscious maximal contraction</td>
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</tbody>
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**Key Threshold Differences**

<table>
<thead>
<tr>
<th>Low Threshold</th>
<th>High Threshold</th>
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<tbody>
<tr>
<td><strong>Slow Motor Unit dominant</strong>&lt;br&gt;Slow / Static&lt;br&gt;and&lt;br&gt;Sustained&lt;br&gt;(non-fatiguing, low load)</td>
<td><strong>Fast Motor Unit dominant</strong>&lt;br&gt;Fast&lt;br&gt;or&lt;br&gt;Fatiguing&lt;br&gt;(high load)</td>
</tr>
</tbody>
</table>
RECRUITMENT DYSFUNCTION: INHIBITION AND DYSFACILITATION

Inhibition and dysfacilitation can be identified as abnormal alteration of normal recruitment

Inhibition relates to a process of neural discharge being actively suppressed by another neural influence. This process is part of normal movement but it may become abnormal in certain situations. Dysfacilitation relates to the utilisation of altered motor control strategies. These altered strategies contribute to changes in thresholds of facilitation and inefficient pattern of muscle activation.

With stability dysfunction, inhibition and dysfacilitation presents as:

- poor recruitment under low threshold stimulus – inefficient slow motor unit (SMU) recruitment
  - (evidence in both the local and global muscle systems)
- delayed recruitment timing
  - (evidence in the local muscle system)
- altered recruitment sequencing
  - (evidence in the global muscle system)

Inhibition & dysfacilitation
- ≠ ‘off’
- ≠ ‘weak’

E.g.1: Pain causes active inhibition of SMU recruitment. The pain may resolve and the mechanism of inhibition may be removed, but dysfacilitation may persist.

E.g. 2: Stress (fear / anxiety) can cause active inhibition of SMU recruitment. Central fatigue contributes to dysfacilitation.

MUSCLE STIFFNESS

Muscle stiffness (i.e. the ratio of force change to length change) consists of two components: intrinsic muscle stiffness and reflex mediated muscle stiffness (Johansson, Sjolander & Sojka 1991).

1. Intrinsic muscle stiffness is dependent on the visco-elastic properties of muscle and the existing actin – myosin cross bridges. This can be affected by hypertrophy or strength training. Hypertrophy (↑ bulk and muscle fibres in parallel) increases intrinsic muscle stiffness but not reflex mediated muscle stiffness

2. Reflex mediated stiffness is determined by the excitability of the alpha motor neurone pool, which in turn is dependent on descending commands and reflexes which are facilitated by the muscle spindle afferent input. This is affected by proprioception and slow motor unit recruitment efficiency.
MUSCLE TRAINING

Motor control training is primarily directed towards restoring normal or ideal recruitment thresholds and strategies (software). It is not based on directly restoring function. Improvements in function are an indirect consequence of recovering SMU recruitment thresholds and restoring more ideal patterns of recruitment.

- Motor control training is progressed by progressively removing load facilitation (unloading) and increasing a recruitment challenge

Strength training affects structure (hardware) of muscle tissue over time. When muscle tissue is loaded and stressed it adapts to stress and hypertrophies and increases the potential to generate force and power. This structural change occurs over a time frame of 6-8 weeks or more

- Strength training is progressed by progressively increasing load

<table>
<thead>
<tr>
<th>Issues related to central (CNS) responses</th>
<th>Issues related to peripheral adaptation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low threshold SMU recruitment</td>
<td>High threshold hypertrophy (SMU &amp; FMU)</td>
</tr>
<tr>
<td>Reflex mediated muscle stiffness</td>
<td>Intrinsic muscle stiffness</td>
</tr>
<tr>
<td>Inhibition</td>
<td>Atrophy</td>
</tr>
<tr>
<td>Sensation of effort</td>
<td>Sensation of force</td>
</tr>
<tr>
<td>Central fatigue</td>
<td>Peripheral fatigue</td>
</tr>
<tr>
<td>Contractile elements influence muscle extensibility</td>
<td>Connective tissue elements influence muscle extensibility</td>
</tr>
</tbody>
</table>

MUSCLE FUNCTION

CLASSIFICATION OF MUSCLE ROLES

STABILISER AND MOBILISER MUSCLE ROLES

Rood, in Goff (1972), Janda (1996) and Sahrmann (2002) have described and developed functional muscle testing based on stabiliser and mobiliser muscle roles.

<table>
<thead>
<tr>
<th>Stabiliser Role Characteristics</th>
<th>Mobiliser Role Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>One joint (mono-articular)</td>
<td>Two joint (bi-articular or multi-segmental)</td>
</tr>
<tr>
<td>Deep (short lever and short moment arm)</td>
<td>Superficial (longer lever, larger moment arm and greatest bulk)</td>
</tr>
<tr>
<td>Broad aponeurotic insertions (to distribute and absorb force and load)</td>
<td>Unidirectional fibres or tendinous insertions (to direct force to produce movement)</td>
</tr>
<tr>
<td>Leverage for load maintenance, static holding and joint compression</td>
<td>Leverage for range and speed and joint distraction</td>
</tr>
<tr>
<td>Postural holding role associated with eccentrically decelerating or resisting momentum (especially in the axial plane – rotation)</td>
<td>Repetitive or rapid movement role and high strain / force loading</td>
</tr>
</tbody>
</table>

Functional Implications of Stabiliser – Mobiliser Roles:

- Muscles with predominantly stability role characteristics (1 joint) optimally assist postural holding / anti-gravity / stability function. Muscles that have a stability function (one joint stabiliser) demonstrate a tendency to inhibition, excessive flexibility, laxity & weakness in the presence of dysfunction (Janda term: ‘phasic’ muscle).
- Muscles with predominantly mobility role characteristics (multi-joint) optimally assist rapid / accelerated movement and produce high force or power. Muscles that have a
mobility function (2-joint or multi-joint mobiliser) demonstrate a tendency to overactivity, loss of extensibility, excessive stiffness in the presence of dysfunction (Janda term: ‘postural’ muscle).

**LOCAL AND GLOBAL MUSCLE ROLES**

Bergmark (1989) developed a model to describe the muscle control of load transfer across the lumbar spine. He introduces the concept of local and global systems of muscle control.

<table>
<thead>
<tr>
<th>Local Muscle System Characteristics</th>
<th>Global Muscle System Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Deepest layer of muscles that originate and insert segmentally on lumbar vertebrae.</td>
<td>• Superficial or outer layer of muscles lacking segmental insertions.</td>
</tr>
<tr>
<td>• Controls the spinal curvature.</td>
<td>• Large torque producing muscles for range of movement.</td>
</tr>
<tr>
<td>• Maintains the mechanical stiffness of the spine controlling inter-segmental motion.</td>
<td>• Global muscles and intra-abdominal pressure transfer load between the thoracic cage and the pelvis.</td>
</tr>
<tr>
<td>• Responds to changes in posture and to changes in low extrinsic load.</td>
<td>• Responds to changes in the line of action and the magnitude of high extrinsic load.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>General features</th>
<th>General features</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Deepest, 1 joint</td>
<td>• Deep 1-joint or superficial multi-joint</td>
</tr>
<tr>
<td>• Minimal force, stiffness</td>
<td>• Force efficient</td>
</tr>
<tr>
<td>• No/min length change</td>
<td>• Concentric shortening to produce range</td>
</tr>
<tr>
<td>• Does not produce or limit range of motion</td>
<td>• Eccentric lengthening or isometric holding to control range</td>
</tr>
<tr>
<td>• Controls translation</td>
<td>• No translation control</td>
</tr>
<tr>
<td>• Maintains control in all ranges, all directions, all functional activities</td>
<td>• Direction specific \ antagonist influenced</td>
</tr>
<tr>
<td>• Tonic recruitment with low load and high load activities</td>
<td></td>
</tr>
<tr>
<td>• No antagonists</td>
<td></td>
</tr>
</tbody>
</table>

**Functional Implications of Local and Global roles:**

- **Local Muscle ‘System’**: The local muscle system is responsible for increasing the segmental stiffness of the spine and decreasing excessive inter-segmental motion and maintaining muscle control during low load tasks and activities. It is independent of the direction of loading or movement and is biased for low load function. The local muscles do not significantly change length during normal activation and therefore do not primarily contribute to range of motion. They maintain activity in the background of all ranges of motion.

- **Global Muscle ‘System’**: The global muscle system is responsible for the production of movement and the control of high physiological load. It is direction and load dependant. The global muscles change length significantly and therefore are the muscles of range of motion. These global muscles may have a primary stability or mobility role.

- **Both the local and global muscle systems must integrate together for efficient normal function. Neither system in isolation can control the functional stability of body motion segments.**
The concepts of local and global muscle systems and stabiliser and mobiliser muscles provide useful frameworks to classify muscle function. However, alone, they have some clinical deficiencies. By inter-linking these two concepts though, a clinically useful model of classification of muscle functional roles can be developed.

### LOCAL STABILITY

**Muscle Role / Strategy**

**Function & Characteristics:**
- ↑ muscle stiffness to control segmental motion / translation
- Controls the neutral joint position
- Contraction = no / min. length change: does not produce R.O.M.
- Activity is often anticipatory (or at the same instant) to expected displacement or movement to provide protective muscle stiffness prior to motion stress
- Recruitment is not anticipatory if the muscle is already active or loaded
- +/- Muscle activity is independent of direction of movement
- +/- Continuous activity throughout movement
- Proprioceptive input re: joint position, range and rate of movement

**Dysfunction:**
- Motor control deficit associated with delayed timing or recruitment deficiency
- Reacts to pain and pathology with inhibition
- ↓ muscle stiffness and poor segmental control
- Loss of control of joint neutral position

### GLOBAL STABILITY

**Muscle Role / Strategy**

**Function & Characteristics:**
- Generates force to control range of motion
- Contraction = eccentric length change: control throughout range
- Functional ability to: (i) shorten through the full inner range of joint motion
  (ii) isometrically hold position
  (iii) eccentrically control the return against gravity and control hyper-mobile outer range of joint motion if present
- Deceleration of low load/force momentum (especially axial plane: rotation)
- Non-continuous activity
- Muscle activity is direction dependent: powerfully influenced by muscles with antagonistic actions

**Dysfunction:**
- Muscle lacks the ability to (i) shorten through the full inner range of joint motion
  (ii) isometrically hold position
  (iii) eccentrically control the return
- If hypermobile – poor control of excessive range
- Poor low threshold tonic recruitment
- Poor rotation dissociation
- Inhibition by dominant antagonists

### GLOBAL MOBILITY

**Muscle Role / Strategy**

**Function & Characteristics:**
- Generates torque to produce range of joint movement
- Contraction = concentric length change: concentric production of movement (rather than eccentric control)
- Concentric acceleration of movement (especially sagittal plane: flexion / extension)
- Shock absorption of high load
- Activity is very direction dependent
- Intermittent muscle activity (very on : off phasic patterns of activity – often brief bursts of activity to accelerate the motion segment then momentum maintains movement)

**Dysfunction:**
- Loss of myo-fascial extensibility – limits physiological and/or accessory motion (which must be compensated for elsewhere)
- Overactive low threshold, low load recruitment
- Reacts to pain and pathology with spasm

(Comerford & Mottram 2001 a&b)
It has been shown that postural adjustments are anticipatory and ongoing (Lee 1999, Horak et al 1984, Carr & Shepherd 1987, David et al 2000, Hodges & Richardson 1996). All muscles can have an anticipatory timing to address displacement and perturbations to equilibrium. All muscles provide reflex feedback reactions under both low and high threshold recruitment tasks. All muscles also demonstrate anticipatory feedforward recruitment when appropriate. However, only muscles with a local stability role exhibit anticipatory timing that is independent of the direction of loading or displacement. Muscles recruiting in a global range related role are direction specific in their anticipatory feedforward responses.
Some muscles do appear to have a single, very specific primary role. They have a specific task orientated role associated with being characterised as having only a local stabiliser role (e.g. Transversus Abdominis, Vastus Medialis Obliquus) or a global stabiliser role (e.g. External Obliquus Abdominis) or a global mobiliser role (e.g. Rectus Abdominis, Hamstrings, Lliocostalis Lumborum). In the presence of pathology and / or pain very specific dysfunctions can develop and are associated with the recognised specific primary role and very specific retraining, or correction has been advocated in treatment (Hodges & Richardson 1996 1997, Hodges et al 1999, Hides et al 1996 2001, O’Sullivan 2000, Jull 2000). This very specific training or corrective intervention is usually non-functional and as such is designed to correct very specific elements of dysfunction. This specific retraining or correction may or may not integrate into normal functional activity. There is no way at the moment to predict or clinically measure automatic integration into normal function. In many subjects this integration has to be facilitated.

Some muscles appear less specific and seem to participate in a variety of roles without demonstrating dysfunction. They appear to have a multi-tasking function associated with being characterised as having the potential to perform more than one role (Comerford 2004). That is, there is good evidence to support both a local role and a global role, or the evidence may support the muscle having a contribution to both stability and mobility roles (e.g. Gluteus Maximus, Infraspinatus and Pelvic Floor). They appear to be able to contribute to combinations of local stabiliser, global stabiliser and global mobiliser roles when required in normal function. In the presence of pathology and / or pain a variety of different dysfunctions may develop. These dysfunctions can be identified as being associated with either or all of the multi-tasking roles and are related to the ‘weak links’ in an individual’s integrated stability system. Treatment & retraining has to address the particular dysfunction that presents, usually needs to be multi-factorial and it should emphasise integration into ‘normal’ function.

**MOVEMENT DYSFUNCTION MODEL**

- Altered Movement Strategies or Poor Postural Alignment
- Inhibition or functional weakness of the global stability muscles
- Increased stiffness or shortening of the global mobility muscles
- Abnormal neuro-dynamic sensitivity
- Imbalance in the global stability system and loss of global control: ‘give’ & restriction
- Direction specific mechanical stress and strain of: articular, myo-fascial, neuro-meningeal and connective tissue
- Cumulative micro-inflammation
- Trauma or Injury (chemical sensitisation)
- Predisposition for recurrence
- Degenerative changes within the movement system
Because restrictions of normal motion are common, the body normally compensates for these restrictions by increasing motion elsewhere to maintain function (this is normal). In normal functional movement, the brain and CNS have a variety of strategies available to perform any functional task or movement. Ideally, the brain and CNS will work out the most appropriate strategy for the demands of the functional task and so long as the trajectory or path of motion is well controlled by a balance of forces in the local and global synergists, and the movement system will cope well.

During functional multi-joint movements a relatively stiffer joint or muscle tends to resist movement, but function is maintained by another joint increasing motion to compensate. Once a joint has developed abnormal compensatory motion, the stabilising muscles and supporting structures (e.g. ligaments) around these joints become too flexible, more lax or provide insufficient stiffness or resistance to motion.

These examples illustrate the inter-relationship between relative stiffness and compensatory relative flexibility of muscle in series (joints above and below each other in the kinetic chain).

While compensation for acquired restriction is a normal adaptive process, compensation that is well controlled is not a stability dysfunction and is usually non-symptomatic. However, compensation that is poorly controlled is maladaptive and contributes to stability dysfunction (‘give’ / uncontrolled movement). The altered patterns of movement that result from these compensatory strategies are observed as altered trajectories of motion. If the brain and CNS are unable to provide the best strategy to control the trajectory of motion then abnormal stress is placed on a variety of neuro-musculo-skeletal structures and pathology may develop.

The inappropriate functional movements that result from these relative flexibility or muscle imbalance situations present as poorly controlled trajectories or paths of maladaptive motion.
DIAGNOSIS OF STABILITY DYSFUNCTION - DIRECTION SPECIFICITY

The direction or plane of movement that one joint is more flexible relative to its adjacent joint is diagnostic. The relative flexibility and the displacement of the PICM (‘give’) diagnose the segment and the direction of dynamic stability dysfunction and are related to the direction of symptom producing movement.

Two identifying features always qualify the diagnosis of stability dysfunction.

1. The site of dysfunction and associated pathology (site of ‘give’ and symptoms) - relate to the site of symptoms
2. The direction of ‘give’ or compensation (direction or position of provocation)

REHAB MANAGEMENT PROCESS

REHABILITATION STRATEGY – FOR MECHANICAL DYSFUNCTION

<table>
<thead>
<tr>
<th>TRANSLATIONAL</th>
<th>RANGE</th>
</tr>
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<tbody>
<tr>
<td><strong>‘GIVE’ or ‘Weak Link’</strong></td>
<td><strong>Facilitate tonic activation of the deep local stability muscles to increase muscle stiffness to control the neutral joint position to provide dynamic stability when there is passive connective tissue laxity</strong>&lt;br&gt;<strong>Surgical reconstruction may attempt to augment stability but this is generally a salvage procedure</strong>&lt;br&gt;<strong>Immobilisation may shorten lax connective structures but this has limited long term effect</strong></td>
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</table>

<table>
<thead>
<tr>
<th>ARTICULAR</th>
<th>MYO-FASCIAL</th>
</tr>
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<tbody>
<tr>
<td><strong>RESTRICTION</strong></td>
<td><strong>Muscle lengthening techniques – sustained stretch, facilitatory stretches (contract-relax) and inhibitory stretches (active inhibitory re-stabilisation and antagonist hold relax)</strong>&lt;br&gt;<strong>Type I METs - muscle energy techniques or Inhibitory MAPs – myotatic activation procedures</strong>&lt;br&gt;<strong>Type II METs – muscle energy techniques or Facilitatory MAPs - myotatic activation procedures</strong>&lt;br&gt;<strong>S.N.A.G.S. and localised mobilisations with movement</strong></td>
</tr>
</tbody>
</table>

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Retrain Dynamic Control of the Direction of Stability Dysfunction
Control the ‘give’ and move the restriction. Retrain control of the stability dysfunction in the direction of symptom producing movements. Use low load integration of local and global stabiliser muscle recruitment to control and limit motion at the segment or region of ‘give’ and then actively move the adjacent restriction. Only move through as much range as the restriction allows or as far as the ‘give’ is dynamically controlled. Control of direction directly unloads mechanical provocation of pathology and therefore is the key strategy to symptom management.

Motor control and co-ordination of direction specific stress and strain

Control of Translation in the Neutral Training Region
Retrain tonic, low threshold activation of the local stability muscle system to increase muscle stiffness and train functional low load integration of the local and global stability muscle systems to control abnormal translation in and around the neutral joint position.

Low threshold recruitment of the local stability system to control articular translation

Rehabilitate Global Stabiliser Control through Range
Rehabilitate the global stability muscle system to actively control the full available range of joint motion. These muscles are required to be able to actively shorten and control limb load through to the full passive inner range of joint motion. They must also be able to control any hyper mobile outer range. The ability to control rotational forces is an especially important role of global stabiliser muscles. Eccentric control of range is more important for stability function than concentric work. This is optimised by low effort, sustained holds in the muscle’s shortened position with controlled eccentric lowering.

Regain Global Mobiliser Extensibility through Range
When the 2 joint global mobility muscles demonstrate a lack of extensibility due to overuse or adaptive shortening, compensatory overstrain or ‘give’ occurs elsewhere in the kinetic chain in an attempt to maintain function. It becomes necessary to lengthen or inhibit dominance or over-activity in the global mobilisers to eliminate the need for compensation to keep function.

Balancing functional length and recruitment dominance between global synergists

(Comerford & Mottram 2003)
INDICATIONS FOR PRIORITY LOW LOAD TRAINING OF THE LOCAL SYSTEM

1. Relevant symptom presentation:
   a. associated with low load normal daily function
   b. unguarded movements
   c. non direction specific pain
   d. associated with static position and all postures (sit, stand & lying)
      (Note: easy to confuse with ‘central pain’)

2. Uncontrolled compensatory articular translation

3. History of insidious recurrence (prevention)

4. Poor voluntary low threshold recruitment efficiency
   • Pain in the region

INDICATIONS FOR PRIORITY LOW LOAD TRAINING OF THE GLOBAL SYSTEM

1. Relevant symptom presentation:
   a. associated with low load normal daily function
   b. unguarded movements
   c. direction specific pain - associated with a particular direction of movement provocation

2. Direction related mechanical pain (one movement ↑ symptoms and another movement ↓ symptoms)

3. Low threshold recruitment imbalance between stabilisers (inefficient / force inhibited) and mobilisers (dominant / overactive)

4. Length – tension imbalance between stabilisers (long / force inefficient inner range) and mobilisers (lack extensibility)

5. History of recurrence - usually related to a precipitating incident where a specific direction of stress or strain is implicated in the mechanism of injury (prevention?)
   • Non-symptomatic uncontrolled (direction specific) ‘give’ (it may be possible to prevent onset or minimise risk)
CONTROL OF DIRECTION

The muscles that have global stability and local stability roles co-activate in integrated patterns to maintain stability during all normal functional activities. All functional activities impose stress and strain forces on the movement system in varying loads and in all three planes or directions of motion. Normal functional movements rarely eliminate motion from one joint system while others move through range. Functional movement rarely occurs in only one plane. However, everybody has the ability to perform patterns of movement that are not habitually used in ‘normal function’ (e.g. pat the head and rub the stomach). Some of these patterns of movement are unfamiliar and feel ‘unnatural’ precisely because they are not habitual patterns of recruitment.

When the stability muscles control and move normal functional loads (even in unfamiliar or non habitual movements), low threshold recruitment should be efficient. Normal functional loads include static holding of postures and dynamic movement through available range of the unloaded limbs and trunk. If low threshold recruitment is efficient then there should be a perceived low sensation of effort to perform these normal activities.

Performance of some of these unfamiliar movements is a test of motor control (skill and co-ordination). The ability to activate muscles to isometrically hold position or prevent motion at one joint system, while concurrently actively producing a movement at another joint system in a specific direction is a test of motor control. The process of dissociating movement at one joint from movement at another joint, or controlling the pattern or path of movement about the same joint, has potential benefits for retraining the stability muscles to enhance their recruitment efficiency to control direction specific stress and strain. The process of dissociating movement at one joint from movement at another joint has potential benefits for retraining the stability muscles to enhance their recruitment efficiency to control direction specific stress and strain. The global and the local stability muscle systems can be trained to recruit in co-activation patterns to prevent movement in a specific direction at a vulnerable (or unstable) joint while an adjacent joint is loaded in that direction. In this way the stability system can be trained to control a specific ‘give’ (site and direction).

RETRAIN CONTROL OF THE DIRECTION OF STABILITY DYSFUNCTION

- These dissociation patterns or ‘recruitment reversals’ are motor control skills. The aim is to effectively reverse the dysfunctional recruitment sequence and control movement at the site of stability dysfunction. This concept is a process of sensory-motor re-programming to regain proprioceptive awareness of joint position, muscle activation and movement co-ordination.

- Position the site of stability dysfunction within its neutral training region and use conscious activation of the stability muscles (both global and local stabilisers) to prevent a specific direction of movement at this site and move the adjacent joint (above or below).

The stability retraining occurs at the joint and in the direction that movement is isometrically controlled (not where the movement actively performed). Throughout the movements, local and global stability muscles are continually active to control the ‘give’ or ‘weak link’.
• Move at the adjacent joint (or same joint – different direction) only as far as:
  o movement is *independent* of the ‘give’ or ‘weak link’
  o stability can be maintained at the ‘give’ or ‘weak link’ (isometric control)
  o any joint restriction allows

• Do slow, low effort repetitions and only move through the range that the weak link can be actively controlled. A general guide is to perform 20-30 slow repetitions or approximately 1-2 minutes of slow repetitions. Occasionally, the body or limb weight has to be unloaded (supported) so that the stability muscles can control the ‘give’. As unloaded control gets easier, progress to controlling the normal functional load of the unsupported limbs or trunk.

• The efficiency of control at the weak link is more important initially than the range of motion at the adjacent joint. “Uncontrolled range is often the cause of symptoms”.

• Perform this type of movement until it starts to feel familiar and natural. Initially, when these low load exercises ‘feel’ difficult or high-perceived effort is used then it is likely that slow motor unit or tonic recruitment is inefficient. However, when the same low load exercise starts to feel easy and less unnatural, then it is likely that there is better facilitation of slow motor unit recruitment. This is a good clinical indicator of improving stability function and motor control efficiency.

• This facilitates the active and eventually automatic recruitment of the local and global stability muscle systems to control movement and to stiffen joint play that may be excessive at the segment of dynamic control dysfunction.

• The aim is to regain awareness of:
  o alignment and postural position
  o movement
  o muscle tension and effort
  o the sensation of ‘easy’ low load holding
  o multi-joint motion differences
  (This is related to improving proprioceptive responses and low threshold recruitment efficiency)

• Direction control movements can also be used to unload pathology, decrease mechanical provocation of pathology and assist in symptom management. This is very useful for early symptom control.
CONTROL OF TRANSLATION (IN NEUTRAL)

Muscles with a local stability role are usually small, mono-articular muscles located deep and close to the axis of joint motion. They are also sometimes referred to as ‘primary’, or ‘deep’, or ‘inner unit’ stabiliser muscles. Their role for functional stability is to maintain relatively continuous, low force, activity in all positions of joint range and in all directions of joint motion. This activity increases local muscle stiffness at a segmental level which controls excessive translatory motion especially in mid range or neutral regions where the passive connective tissue restraints such as ligaments and capsules provide less support. Their recruitment does not functionally limit range of motion; rather they control excessive translation while allowing full range of movement in all directions and in all functional tasks.

They provide this control through several mechanisms:

i. Increased force closure around neutral (via segmental stiffness and compression)

ii. Increased deep fascial tension to maintain relative alignment of motion segments throughout range of motion

iii. Increased intra-abdominal pressure (trunk or ‘core’ muscles)

They often activate in an anticipatory feedforward mechanism prior to functional limb or trunk movements used by the body to maintain stability during a sudden or unguarded movements. This feedforward mechanism provides joint protection and support before movement related load is imposed on the joint system. This anticipatory response appears to be most important to provide stability during a perturbation or displacement challenge e.g. stepping onto an unstable or slippery surface or controlling a sudden unguarded movement. For planned, slow movements using normal functional loads this feedforward anticipatory response does not seem to be so important. It appears that if the demand is slow and low load then feedback processes may adequately provide the required stability. Muscles that provide this local stability role also appear to maintain a continuous, tonic pattern of activity throughout functional movements independently of respiratory function (Hodges and Gandevia 2000, Saunders and Hodges 2003) or of direction and range of movement (e.g. VMO:. Richardson & Bullock 1986)

Even though the local stability and the global stability muscles recruit in integrated patterns to maintain stability during all normal functional activities and postures, the muscles with a local stability role should be able to demonstrate (or should be easily trained to perform) specific recruitment skills. Although everybody has the ability to perform these patterns of movement that are not habitually used in ‘normal function’, some of these patterns of movement are unfamiliar and feel ‘unnatural’ precisely because they are not habitual patterns of recruitment.

When the stability muscles control normal functional loads (even in unfamiliar or non habitual movements, low threshold recruitment should be efficient. Normal functional loads include static holding of postures and dynamic movement through available range of the unloaded limbs and trunk. If low threshold recruitment is efficient then there should be a perceived low sensation of effort to perform these normal activities.

Performance of some of these unfamiliar movements is a test of motor control (skill and co-ordination). The ability to activate specific muscles isometrically to consistently increase stiffness in order to control translatory motion at joint segments independently of respiratory function is a test of motor control.
RETRAIN LOCAL CONTROL OF THE NEUTRAL REGION

- **Specific activation** or setting contraction of the deep local stabiliser muscles (Richardson et al 2004, Hodges 2003, Jull et al 2002, Richardson & Jull 1995, Hodges and Richardson 1996, Hides et al. 1994) in the neutral joint position. For the spine this is in the **neutral spinal posture** (Hamilton 1995, 1998) and for the peripheral joints this is in joint neutral.

- The contraction is **biased for the local stability muscle role**. Though, clinically, it seems acceptable to allow some co-activation of the synergistic global stability muscles under some conditions. The local and global stability muscles co-activate synergistically in normal function. However, it is important that the local stability muscles dominate the contraction and the global stability muscles only recruit with low load, low threshold activation. Also, there must be no significant increase in activation of the global mobility muscles.

- The contraction is **isometric**. No movement should occur at the region / segment of dynamic control dysfunction.

- The contraction should be biased for slow motor unit recruitment (low force).


- It is essential that this consistent low force contraction is independent of normal relaxed respiratory function.

- It is a **conscious** activation requiring **motor planning** and **proprioceptive feedback**.

- Optimal **facilitation** is dependent on identification and elimination of **substitution** strategies, co-contraction rigidity and overload or fatigue. Decrease the effort of activation or decrease load until contraction can be performed without substitution.

- High or even maximum **perceived effort** is permissible initially, but as control and functional integration return low effort activation should dominate. There should be no fatigue or substitution. Increase effort of activation or increase load until contraction of the stability muscle is palpable or observable. Perform the activation slowly and hold the contraction when it is achieved so that overflow into substitution does not occur. Note how much 'perceived' (sensation of) effort is required to perform the contraction correctly.

- Integrate local muscle training into ‘normal’ function. First, train non-functional ‘specific’ recruitment strategies to decrease the threshold for slow motor unit recruitment. Then maintain the trained recruitment in presence of fast, small range, low force, and unpredictable displacement challenges to facilitate feedforward specificity.

- Do not combine local muscle dominant recruitment & overload or strength training.
**CLINICAL GUIDELINES FOR RETRAINING LOCAL STABILISER ROLE**

- Palpate for the correct activation
- Observe for:
  - Correct contraction pattern
  - Tonic (slow motor unit) recruitment (no fatigue under low load)
  - No substitution
- Breathe normally with a consistent, sustained contraction – no co-contraction rigidity
- Low force sustained hold for 10 seconds and repeat 10 times (normal breathing)
- Perform in a variety of different functional postures
  - Correct contraction pattern
  - Tonic (slow motor unit) recruitment (no fatigue under low load)
  - No substitution
- Recruitment of the stability muscles to control joint neutral must be non-provocative and pain free.

There appears to be a ‘window’ of correct recruitment opportunity between:

(i) sufficient sense of effort to achieve adequate activation

and

(ii) excessive effort and substitution or co-contraction rigidity

- Integrate non-functional motor control skills into normal function
  Integrate into normal function

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**Specific Activation of Stability Muscle**
- low threshold (tonic)
- consistent contraction independent of respiration
- functional joint positions
- no phasic recruitment
- no substitution
- no co-contraction rigidity

**Fast Track into Function**
- integrate local & global control
- add functional loads
- integrate into normal function

**Facilitation Strategies**
- cognitive awareness
- feedback - tactile, visual, tech
- proprioceptive input
- co-activation
- automatic reflex recruitment
- fascial preload
CONTROL THROUGH RANGE

Muscles with a global stability role are characterised as mono-articular muscles with a primary role for maintaining stability throughout range. As well as their ability to co-ordinate and dissociate rotation through the kinetic chain (dealt with in control of direction) these muscles have the function of producing, holding or preventing movement. The functional stability role is to generate torque and provide eccentric control of inner and outer range of joint motion.

These muscles are required to have the ability to:
1) Concentrically shorten to synergistically contribute to joint motion into the full physiological inner range position. This position is the combination of motion in all three planes of the specific muscle’s action (e.g. Posterior Gluteus Medius should be able to shorten efficiently and demonstrate the ability to move the unloaded leg through the combination of full extension, lateral rotation and abduction of the hip).
2) Isometrically hold this (or any other) position to sustain postural alignment or support functional trunk or limb load.
3) Eccentrically control the return through range (limb lowering against gravity). The muscles are required to eccentrically control or decelerate rotational strain at all joints especially the trunk and girdles. They should contribute significantly to rotation control in all functional movements.
4) Control whatever functional range is available. Therefore, the global stabilisers should demonstrate efficient control of both normal and hypermobile ranges of motion.

For normal functional loads and movements (i.e. support or movement of the unloaded trunk or limbs) these muscles should activate with predominately low threshold recruitment.

CHANGES IN MUSCLE ASSOCIATED WITH CHANGE IN LENGTH

Stability muscles are required to maintain tension in their middle to inner (shortened) range to maintain good postural alignment (e.g. iliacus to maintain pelvic position and the back extensor stabilisers to maintain lumbar lordosis to hold good sitting posture). If a stabiliser muscle is elongated (due to habitual use in lengthened range) then it will become force inefficient (more so than normal) in its shortened range. (Gossman et al 1982)

Key Points: length-tension changes
- A relative length change in a muscle, affects that muscle’s recruitment and force efficiency at different points in range
- Good postural alignment and functional stability often requires efficient stability muscle holding in its inner to middle (shortened) range
- Elongated muscles are efficient in their lengthened position but are inefficient in their shortened (functional stability) position
- Shortened synergists, which are efficient in the functional stability position, tend to become the dominant synergist because they are more efficient here and fatigue less easily than an elongated synergist.
In the presence of pain or dysfunction the stabiliser synergists usually test long or weak at manual muscle testing while the mobiliser synergist usually tests short or over-active. (E.g. in back, pelvic or hip pain the posterior gluteus medius often tests weak in inner range abduction while tensor fascia latae tests strong and is the dominant synergist in inner range abduction).

MOTOR CONTROL AND RECRUITMENT ISSUES

An alternative treatment strategy could be to attempt to correct the imbalance by altering the recruitment efficiency of synergistic muscles. The work of Wiemann et al (1998) lends support to this hypothesis. They differentiate between the relative origin-insertion distance (“stretch capability”) and the joint angle or position that a muscle can generate its optimal or maximal strength (“functional length”).

If the length-tension curve of the dysfunctional stabiliser muscle can be ‘bent’ towards inner range then it would be more efficient in this range. The point in range where peak tension (“functional length”) is generated would shift towards inner range. Likewise, the point in range that the muscle failed due to physiological insufficiency (cannot actively shorten any further) would shift further into inner range. At the muscle test position in range, the muscle would generate relatively more tension (test stronger) and be more efficient without hypertrophy or specifically getting stronger or shorter.

If normal function and full outer range of movement was maintained during this process then it is unlikely that the outer range end of the length-tension curve would move (no loss of available range). It is hypothesised that the length-tension curve elongates to the left and becomes more efficient over a greater range, especially the inner (shortened) range.

**Key Points: recruitment influences on ‘functional length’**

- Functional length is the term that describes the point in range where a muscle has greatest force efficiency
- Strength training does not change the functional length
- Functional length changes in response to the range of repeated, sustained or habitual use
- Changing functional length does not change the available range of motion
- A relative change in the range of habitual use affects recruitment and force efficiency

Clinically, muscles that perform a global stability role would be considered to be dysfunctional if they were unable to:

(i) Concentrally shorten into the full physiological inner range position.
(ii) Isometrically hold this position.
(iii) Eccentrically control the return through range (limb lowering against gravity).
(iv) Control whatever functional rotation range is available.
RETRAIN GLOBAL CONTROL THROUGH RANGE

1. RE-TRAIN LOW THRESHOLD RECRUITMENT (LOW FORCE / LOW LOAD EXERCISE)

The stabilisation force must be low actual effort - in the range of less than 30% of maximum voluntary contraction (MVC), to ensure recruitment of low threshold tonic fibres for stability function. Trying too hard, maximally contracting or exercising with too heavy a load where the contraction force increases to greater than 30% of MVC necessitates the recruitment of more phasic fibres.

If activating the muscle is difficult it is permissible to use more than 30% sensation of effort initially, but the movement must become ‘easy’ and low effort before it is progressed to a higher level. High levels of perceived effort are allowed, so long as there is no fatigue and no substitution with inappropriate muscles or recruitment patterns.

2. RE-TRAIN HOLDING TIME

Increasing the holding time of muscles that have a stability function has priority over strengthening. This is to facilitate recruitment of tonic fibres and train specificity of anti-gravity holding function. If a muscle contraction fatigues too quickly under low physiological load then it is likely that it was recruiting predominantly phasic fibres. The ability to sustain this contraction seems to be important for prevention of recurrence and for return of function (Hodges and Richardson 1996, Richardson and Jull 1995, Hides et al. 1996).

Optimal holding times may vary for different muscles. The general clinical guide: a 10-second, consistently sustained contraction repeated 10 times.

3. RE-TRAIN IN THE MUSCLES’ SHORTENED POSITION

The position of limb movement that a global stabiliser muscle can achieve when it shortens may be quite a few degrees less than the joint's inner range. The low force, sustained contractions ideally should be performed in the muscle's shortened range, and at the point that can be comfortably held for 10 seconds, to facilitate muscle inner range control and tonic recruitment.

4. RE-TRAIN ECCENTRIC CONTROL OF LIMB LOWERING

Recruitment issues are an important feature of eccentric control. The eccentric control of the active movement from the muscle’s shortened position is important to retrain as part of the low force, sustained hold. Poor eccentric control is commonly observed clinically. Eccentric control of the outer range of movement is especially important for stability function. If hypermobile range of motion is evident, eccentric control of that range has high priority.

5. ROTATION CONTROL

Because muscles that have a global stability role are the muscles that are anatomically and biomechanically orientated to control rotation efficiently, it is important to have reasonable rotation dissociation ability prior to training the global stabiliser function. The rotatory component of global stabiliser muscle action must be controlled during the low force concentric shortening, sustained hold and eccentric lengthening.
CONTROL OF EXTENSIBILITY

The muscles with a global mobility role are the multi-articular primary force generators of motion. They are biomechanically advantaged for speed of motion or the production of large range of motion. These muscles are particularly efficient in the sagittal plane, but even though they can generate high forces and can be powerful rotators, they are not so effective in decelerating momentum, controlling range of motion or controlling rotational forces within a joint system. They are inefficient at providing segmental control of physiological and translational motion.

Muscles, which primarily have a mobilising role, are required to have adequate extensibility (stretch capability) to allow full physiological and accessory (translational) range of joint movement. Global mobiliser muscles may be considered dysfunctional when they are present either as short and lacking extensibility or as over-active resulting in increased relative stiffness. This clinically present as:

a) Loss of muscle extensibility (altered length or stretch capacity). This loss of extensibility is usually associated with contractile tissue changes, but may also involve connective tissue change.

b) Excessive dominance of the mobiliser muscle over its stabiliser synergists during low load ‘normal’ functional movements or under low load testing (altered recruitment threshold). This presents as excessive relative stiffness as compared to relatively more flexible antagonists or stabiliser synergists.

Myofascial restrictions or excessive relative stiffness may directly contribute to stability dysfunctions by holding a joint system in a position or direction of ‘give’. E.g. a ‘short’ or ‘stiff’ rectus abdominis can directly hold the lumbar spine in increased flexion.

Myofascial restrictions or excessive relative stiffness may indirectly contribute to stability dysfunctions by requiring that an adjacent joint system must increase its mobility or decrease its relative stiffness to maintain normal function. This compensation can develop into a stability dysfunction. E.g. a ‘short’ or ‘stiff’ hamstring muscle, which limits hip flexion, can indirectly cause the lumbar spine to compensate by increasing flexion to maintain forward bending function. If the back extensor stabilisers lack efficient control of the increased lumbar flexion range then a stability dysfunction develops.

REGAINING MUSCLE EXTENSIBILITY

In general terms there are three basic types of lengthening techniques: (i) sustained stretch; (ii) autogenic stretch and (iii) reciprocal stretch. Any lengthening technique will lengthen shortened muscle, but indifferent situations; some are better than others are.

- **Sustained stretch** is best for connective tissue and collagen (e.g. fascia, capsule contracture, increased connective tissue in muscle, scar tissue). This is optimally performed as a low force, long duration stretch using limb load and gravity sustained for approximately 30 seconds to 2 minutes and repeated 2-3 times.

- **Autogenic inhibitory** (sometimes call ‘facilitatory’) stretch (e.g. Post Isometric Relaxation, Hold-Relax or Contract-Relax techniques) is probably best for contractile tissue that is atrophied and short (e.g. post immobilisation muscle shortening). These techniques are based upon autogenic inhibition, which is controlled by the golgi tendon organs.
• **Reciprocal inhibitory stretch**, (e.g. Antagonist Hold-Relax or Active Inhibitory Restabilisations) are probably best for overactive or hypertrophied contractile tissue (e.g. muscle imbalance). These techniques are based upon reciprocal inhibition, which is controlled by the ‘gamma loop’ within the muscle spindle stretch reflex.

**ACTIVE INHIBITORY RESTABILISATION (AIR)**

Where short muscles are overactive and dominate their synergists or if painful or inflammatory pathology is present ballistic stretches are contraindicated and contract-relax type techniques may well be counter-productive. If a muscle is already overactive with preloaded spindles biasing the spinal motor-neurone pool, a technique that actively contracts the offending muscle (and increases spindle firing) may not be the most appropriate when there is a need to minimise spindle influences.

An inhibitory lengthening technique called **active inhibitory restabilisation (AIR)** is proposed. It involves the operator gently and slowly lengthening the muscle until the resistance causes a slight loss of proximal girdle or trunk stability. The operator then maintains the muscle or limb in this position. The subject is then instructed to actively restabilise the proximal segment that lost stability and sustain the correction for 20-30 seconds and repeated 3-5 times.

This active proximal restabilisation provides the force of the stretch, which the subject controls, for safety. More importantly, it reciprocally inhibits the overactive contractile elements of the tight muscle. A further bonus is that the subject ideally uses a proximal stabiliser muscle (rather than a distal limb mobiliser) to provide the antagonistic inhibition and therefore facilitates and re-enforces holding work for appropriate stabilisers.

**INTEGRATION INTO NORMAL FUNCTION**
A. Treatment of the pain-producing lesion: Relieve pain and spasm, assist the healing of the actual lesion, assess and correct adverse neural mechanics and improve the biomechanics of the acute dysfunction via manual techniques, electrotherapy, relaxation etc.

B. Identify and correct the dynamic stability dysfunction and muscle imbalance that may have contributed to the development of the pathology.

C. Manage chronic non-mechanical pain issues

Restrictions should be mobilised as early as possible in the rehab process, so long as the ‘give’ is controlled! The earlier the restriction is eliminated the less need for compensation to maintain function and the easier it is to retrain stability recruitment.
REHABILITATION PROGRAMME

General guide: Approximately 2-4 exercises initially, twice daily. Increase exercises as the stability programme progresses and is integrated into function. A patient would rarely have any more than 6-8 exercises to do at any one time. This programme takes 20-30 minutes per session depending on familiarity with the exercises. They should not be rushed. Each exercise should be performed slowly, with control and ‘feel’ for precision of movement. Most exercises should be performed in a relaxed manner with minimal effort. If the exercise is ‘hard work’ or physically demanding it is probably being performed to hard or at too high a level for motor control re-training to be effective.

Points to consider:
- Different individuals learn in different ways and respond to different facilitation strategies and options
- Motivation & compliance: Structured vs. non-structured; Specific vs. non-specific
- Mechanical vs. non-mechanical issues
- Start rehab programmes with local & global exercise but it is OK to start with just global exercises or just local exercises
- A couple of exercises done well often achieves more than many exercises done poorly
REFERENCES AND RELATED READING


Comerford MJ 2004 Core Stability: priorities in rehab of the athlete SportEx Medicine 22:15-22


Goff B 1972 The application of recent advances in neurophysiology to Miss R Rood’s concept of neuromuscular facilitation Physiotherapy 58:2 409-415


Hamilton C, Richardson C 1998 Active control of the neural lumbopelvic posture; a comparison between back pain and non back pain subjects Vleeming A, Mooney V, Tilsher H, Dorman T, Snijders C 3rd Interdisciplinary World Congress on Low Back Pain and Pelvic Pain Vienna Austria

Hamilton C, Richardson C 1995 Towards the development of a clinical test of local muscle dysfunction in the lumbar spine In proceedings of the 9th Biennial Conference of the Manipulative Physiotherapists Association of Australia. Gold Coast


Hides JA, Richardson CA, Jull GA 1996 Multifidus recovery is not automatic after resolution of acute first-episode low back pain Spine 21(23): 2763-2769

Hides JA, Richardson CA, Jull GA 1995 Magnetic resonance imaging and ultrasonography of the lumbar multifidus muscle: comparison of two different modalities Spine 20:54-58


Hodges PW, Gandevia SC. 2000 Changes in intra-abdominal pressure during postural and respiratory activation of the human diaphragm J Appl Physiol 89(3): 967-76

Hodges PW, Richardson CA 1999 Transversus abdominis and the superficial abdominal muscles are controlled independently in a postural task. Neurosci Lett 265(2): 91-94
Hodges PW, Richardson CA 1997 Feedforward contraction of transversus abdominis is not influenced by the direction of arm movement. Experimental Brain Research 114(362-370)

Hodges PW, Richardson CA 1996 Inefficient muscular stabilisation of the lumbar spine associated with low back pain: a motor control evaluation of transversus abdominis Spine 21(22): 2640-50

Horak FB, Esselman P, Anderson ME, Lynch MK 1984 The effects of movement velocity, mass displaced, and task certainty on associated postural adjustments made by normal and hemiplegic individuals Neurol Neurosurg Psychiatry Sep; 47(9): 1020-8

Janda V 1996 Evaluation of muscle imbalance In: Liebenson C (eds) Rehabilitation of the Spine Williams & Wilkins Baltimore


Saunders, S & Hodges 2003 Changes in three-dimensional trunk kinematics and trunk muscle activation with changes in locomotor mode and speed Australian Conference of Science and Medicine in Sport and Third National Sporting Injury Prevention Conference "Tackling the Barriers to Performance and Participation" October 25-28 2003 National Convention Centre Canberra

Sahrmann S A. 2002 Diagnosis & Treatment of Movement Impairment Syndrome. Ist ed Mosby USA
