Strength Versus Stability Part II; Limitations and Benefits

Sean GT Gibbons and Mark J. Comerford

Introduction

There is a general consensus that exercise is beneficial in the rehabilitation of low back pain (Abenhaim et al, 2000; Mooney, 1995a; Mooney, 1995b, Risch et al, 1993). The mechanisms are unclear and descriptions have been non - specific in the literature (Campello et al, 1995; Mooney, 1995b; Dillingham and Delateur, 1995). In strengthening rehabilitation, there are limitations to the type and method of rehabilitation protocols, and to the interpretation of measurement of change (Nicolaisen and Jorgensen, 1985; Newton et al, 1993a; Newton et al, 1993b; Hupli et al, 1996). Other aspects in relation to problems with interpreting the literature have been highlighted (Gibbons and Comerford, 2001). Part one of this paper described some of the current concepts in stability rehabilitation to help understand the differences in strength and stability. In part two of this paper, the limitations of strengthening programs are highlighted as well as the possible mechanisms that strengthening can help in the management of low back pain. This may help in understanding and critically evaluating literature relating to muscle function, strengthening, stability and exercise programs.

Limitations of strengthening programs

Local stability muscle dysfunction

Research has shown that local stability muscles exhibit a motor control deficit and is not related to strengthening. In the lumbar spine, transversus abdominus, the deep segmental fibres of multifidus and the posterior fascicles of psoas major are local stabilizers. To date, the only evidence of this dysfunction being rehabilitated is with specific low load exercises (Richardson et al, 1999a; O'Sullivan, 1997). There is preliminary evidence to suggest that strengthening transversus abdominus may increase or prolong the dysfunction (Richardson and Hodges, 1996, Richardson et al, 1999b). It is common in work hardening programs or in chronic pain management to work through pain. This may be important depending on the dominant pain mechanism, but it should be noted that the presence of pain might alter the normal recruitment of the local stability system (Richardson et al, 1999b). With the research evidence so far, it is unlikely that strengthening or functional activity programs will effectively rehabilitate the motor control deficit that exists in local stability system.

Slow motor unit recruitment

When load is added to a movement there are predominantly fast motor units recruited (McArdle et al, 1996). For optimal stability and postural holding, it is better to use low load, or minimal load (less than 25% MVC) to primarily recruit slow motor units. Exercise programs often go close to the point of fatigue or add load in excess of 25% MVC. Even an appropriate exercise may not be beneficial because this will encourage the recruitment of fast motor units (Jones et al, 1989). This is deleterious for a rehabilitation program because it is only a small portion of the day that our body actually uses a high load (Pheasant, 1991).

Motor control stability rehabilitation and core stabilization

There is a difference in motor control stability rehabilitation to increase muscle stiffness to enhance stability and 'core stabilization' that strengthens proximal muscles.

Core stabilization does not:

(1) primarily recruit slow motor units. Adding load, primarily recruits fast motor units and slow motor units may be recruited along with them. This is non-specific for slow motor unit recruitment.

(2) differentiate between synergistic stability or mobility muscles. Under load, all must contribute to the movement. Strength training may possibly create interference if the local stabilizer recruitment is overloaded. Overloading may possibly interfere with slow motor unit recruitment in the presence of slow motor unit efficiency dysfunction.

Sensation of effort

Sensation of effort is not considered in exercise regimes. It is common for clients to report a low load as being perceived as a high load, but it is also feels easier to sustain a higher load when there is a deficit of proprioception. Grimby and Hannerz (1976) specifically link deficiency of proprioceptive input to inefficiency of slow motor unit recruitment and the perception of low load exercises being perceived as high load or hard work. Many rehabilitation programs assess clients before the start (i.e. functional capacity evaluation) of the program so the starting point may be at very low loads. This may be less than 25% MVC and recruit slow motor units so some clients may benefit from this.

Relative flexibility

Strengthening regimes do not address the "give" and "restriction". This involves stabilizing the "give" and moving the "restriction" (Comerford and Mottram, 2000). Relative flexibility is not considered and therefore, there is no dissociation between different body segments. Sahrmann (1992, 2000) emphasizes the importance of dissociating faulty movement patterns because they can be the cause of pathology. Some exercise instructors can identify and eliminate poor techniques with visual, verbal, or tactile feedback. Although clients with good proprioception may do well with this feedback, individuals with poor proprioception or poor stability may not respond so well.

Stretching

Stretching is considered an important component to rehabilitation programs. Sarhmann (1992, 2000) recommends that home stretches or active lengthening of short muscles come last. Stretching may reproduce the "give" at the site of relative flexibility if done in the presence of stability dysfunction. Care must be taken if stretching is performed as a warm - up prior to a rehabilitation program. The global mobilizers are the muscles that are generally found to be short and overactive (Janda, 1985). The global mobility system is dysfunctional when it responds to low loads like postural sway (i.e. gluteal insufficiency and overactive hamstrings in a single leg stance). Slow motor units are recruited during a sustained stretch (Burke, 1968). Stretching a mobilizer muscle may encourage them to respond to low loads by encouraging slow motor unit recruitment (Clarke, 2000). It may be better to encourage slow motor unit recruitment in the local and global stability systems and let the global mobilizers dominate for load and speed with fast motor unit recruitment (Comerford and Mottram, 2000).

Rotational control

Strengthening programs often involve a significant amount of sagittal plane movements. During these exercises there is little rotational control training or specific training of deceleration of rotation. Rotational exercises involving load or speed (fast motor unit recruitment) do not address controlling compensatory movement patterns (relative flexibility). Rotational exercises involving load or speed can be beneficial at higher stages of a rehabilitation program, but optimal postural holding and rotational control is needed before progressing to strengthening. Rotational control is a key defining characteristic of the global stability system, therefore this muscle group will remain dysfunctional if not appropriately rehabilitated. Under stability assessment, rotational movements are often dysfunctional with poor ability to dissociate movements. With poor dissociation, there is a lack of ability to rotate one joint independently from its adjacent joints. A dissociation test may appear normal with good proximal stability, however there is often a 'shaking' motion seen in the distal limb. The 'shaking' motion is due to a loss of rotational control that the body tries to compensate for by co-contraction rigidity. Co-contraction rigidity presents when the global muscle system attempts to isometrically eliminate rotation instead of eccentrically controlling rotational load and momentum. The authors' hypothesize that in an attempt to complete the movement, the central nervous system alternately holds and releases global muscles, (a shaking motion) because they lack the ability to eccentrically control the movement in a smooth fashion. Fixing the limbs using equipment, particularly in the sagittal plane, will not assist in rehabilitating rotational control. This is exaggerated when the load is increased.

Inner range holding, eccentric control and muscle balance

Peak force is generated in the mid range of a muscle. High load exercises tend to focus training in this range. Exercises in strengthening programs often do not train to inner range, through range or focus on the eccentric component of the exercise. When they do, there is no dissociation or holding time, which is characteristic of the global stability system. The global stability muscles should be able to move the limbs through range or control the trunk while the limbs move through range. If not, there will be a loss of stability during functional movements. During resisted exercises, groups of muscles are recruited to perform movements (global mobilizers and global stabilizers co-contract). Because of this there may be problems with this approach. When a mobiliser is dominant over its stabiliser synergist, it will continue to dominate it during the strength training. Both muscle groups will increase in strength and there will be no change in the relative balance of contribution in favour of the stabilizer. Many exercises in strengthening programs are aimed specifically at the mobilizing or power muscles. In the presence of pathology or dysfunction these muscles are already short / overactive and may increase the dysfunction that already exists.

Proprioception

General exercise programs do not usually provide a specific proprioceptive challenge. There is a proprioceptive deficit in subjects with low back pain (Brumagne et al, 2000) and neck pain (Revel et al, 1991). A significant amount of proprioception is gained from the afferent information provided by muscle spindles. As well as this, slow motor units are more tightly bound into the muscle spindle loop and therefore most easily recruited by spindle afferent input. Spindles are almost absent in regions consisting mainly of fast motor units (Maier et al, 1972; Johansson and Sojka, 1991). With increased proprioception there is increased slow motor unit recruitment and increased muscle stiffness (Wagman, et al 1965). This implies that with decreased proprioception, there is decreased slow motor unit recruitment and less muscle stiffness. This is in fact what Grimby and Hannerz (1976) found, as mentioned above. Using resistance distal to limbs may not provide the specific proprioception input that is needed to control the neutral joint position in the spine (Brumagne et al, 2000; Parkhurst and Burnett, 1995). Some functional regimes may provide a specific proprioceptive challenge, however without addressing the relative flexibility, people with poor proprioception will unlikely do well (Figure 1). Subjects with a history of low back pain have difficulty repositioning their spine in neutral compared to subjects with no history of low back pain (Brumagne et al, 2000). This proprioceptive deficit does not return and needs specific retraining of the neutral spine position (Hamilton, 1995). This may have significant overlays in the development

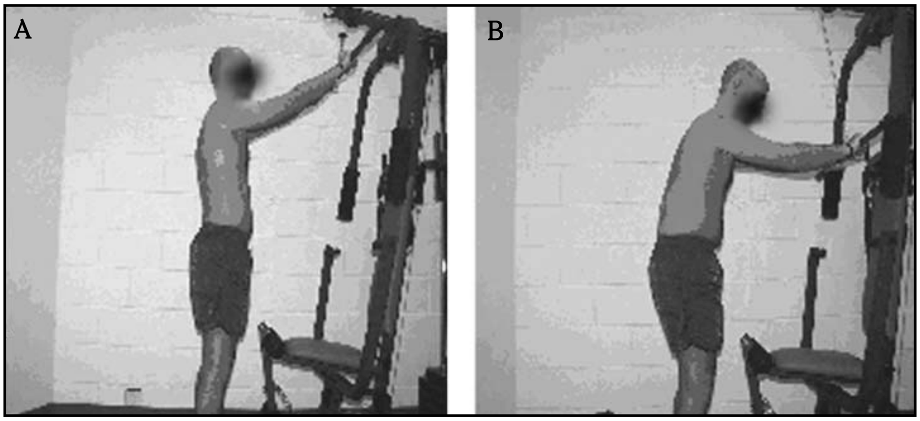

Figure 1: (A) The client is performing pull down exercises in standing. Note the relative increase in flexion (B) during the concentric phase.The spine was not in a neutral position to start (A) and moves further away from neutral with increased flexion (B). There is high load used that will facilitate fast motor units, and the movement dysfunction, or relative flexibility, is not addressed.

of central pain mechanisms (chronic pain). In the presence of a proprioceptive deficit, the dorsal horn cells increase their receptive fields (Woolf, 1994). This is one of the alterations in processing that occurs in the development of central pain mechanisms (Gifford, 1998). Specific low load exercises to enhance slow motor unit recruitment involving spinal muscles may be most efficient at rehabilitating proprio-ceptive deficits. This may be best achieved with the spine in a neutral position. This is a position where there is minimal support from the passive osteo-ligamentous system and where the active muscle system is essential for dynamic stability. There will be minimal feedback from other proprioceptive sources such as ligaments, and the muscle spindles will be responsible for providing this feedback.

Pathology

Exercise programs do not specifically address pathology. Neurodynamic pain sources will respond differently to movement than myofascial tissue. Neural tissue may need to be mobilized (Shacklock, 1995) however, some neural tissue is reactive and irritable when mobilized (Elvey, 1986; Butler, 1993). Irritable neural responses may be due to relatively normal neural tissue sliding over an excessive or a hypermobile range in a dysfunctional movement system. The hypermobile motion segments will need to be stabilized to allow the sensitive neural tissue to settle. Tensile mobilization may be provocative for this neural tissue (Comerford and Mottram, 2000).

Movement dysfunction

The underlying movement dys-function is not considered. Clients with a lumbar extension "give" may not be ready to start doing exercises in prolonged standing (Figure 2). This cannot be addressed by increasing standing tolerances. Nothing is being done to change the underlying muscle imbalance or relative flexibility or slow motor unit recruitment deficiencies. In addition to this, the presence of pain may alter the normal recruitment of the local stability system (Richardson et al, 1999b).

Benefits of strengthening programs

Placebo and psychosocial benefit

Exercise programs can serve as a placebo even if it is completely inappropriate. Clients believe being stronger will help them so exercise helps them. General exercise releases the body's natural pain analgesics (endorphins etc) (Howley, 1976). This may be more important depending on the dominant pain mechanism (Lindstrom et al, 1992). Fear avoidance has been shown to be an outcome indicator for success after an episode of low back pain (Watson, 2000). Those who perceive their health status positively are the ones more likely to exercise. The decision to begin an exercise program is motivated by the perceived beneficial health effects of exercise and continuing with the program is a function of feelings of well being and pleasure (Dishman et al, 1985; Caruso and Gill, 1992). Participating in an exercise program in itself will have a positive psychosocial impact and will therefore increase the likelihood of a more positive outcome (Risch et al, 1993; Abenhaim et al, 2000).

Tissue mobilization

Even when the exercise reproduces the stability dysfunction (give) and causes pain, it can be perceived as doing good rather than harm. Likewise, even though the pathology and "give" are not addressed, the tissue may need to be mobilized and it is possible this

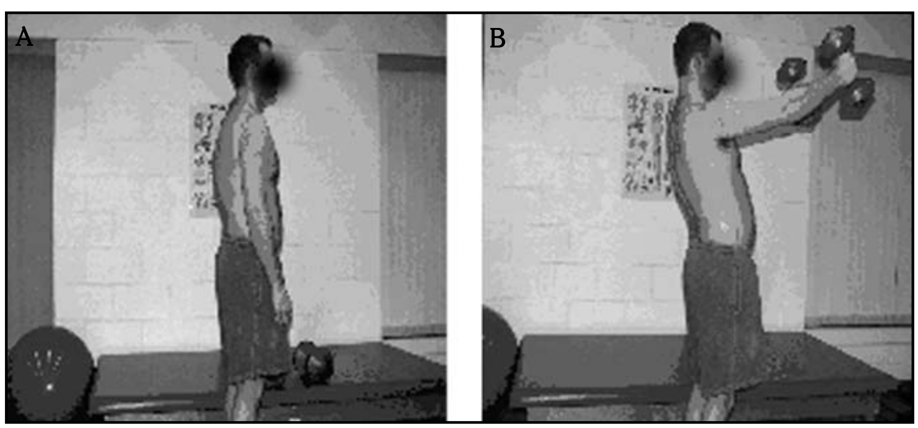

Figure 2: Figure 2: The client is performing general shoulder exercises in standing (A). Note the increase in sway posture when the load is added (B).

can be done by chance with a general program (i.e. biceps brachii strengthening and upper limb tension test 2a, or knee extension exercises and lower limb neural mobilization).

Slow motor unit recruitment

Some clients are assessed before they are given an exercise program and start at very low loads. This may encourage slow motor unit recruitment and improve postural holding. This outcome may also depend on the level of local stability, proprioception and the relative flexibility that the client has.

Load facilitation and mechanical facilitation

There is an increase in strength seen in the initial phase of strengthening programs that is not related to hypertrophy (McArdle et al, 1996). This is generally considered due to training and skill (Rutherford and Jones, 1986; Bernardi et al, 1996) or increased activation of prime movers (Hakkinen and Komi, 1983; Moritani and DeVries, 1979). There is a discrepancy in the literature as to whether all motor units are active during a maximum voluntary contraction (Jones et al, 1989). Some authors describe a 'reserve' of motor units that do not get used, but the literature is conflicting (Sale, 1988). The significance of this in rehabilitation is unclear. It may be possible that some individuals who are sedentary may benefit from a general strengthening program that facilitates motor units. For example, Stubbs et al (1998) mechanically stressed the inter-spinal ligaments of felines and produced a reflex contraction of multifidus. Load production in humans through strengthening is non specific for slow motor unit recruitment and likely only benefits fast motor unit recruitment (Sale, 1988; Jones et al, 1989), but may benefit generally inactive individuals.

Intrinsic muscle stiffness

It is possible that general strengthening programs will help symptoms by increasing intrinsic muscle stiffness to control the "give" (McArdle et al, 1996). There may also be associated shortening of the fascial slings proposed by Pool-Goudzwaard et al (1998). This benefit may not be long lasting. When placed in situations where speed, end range movements or rotational movements are required, there will be a loss of control of functional stability. The muscles required to control this cannot be rehabilitated efficiently with general strengthening programs and the strain mechanism is likely to return.

Stability and Strength

It should be noted that strength training is needed for a certain population of clients, particularly sports people or clients involved in jobs with manual handling. This needs to be addressed, but sequential to or in conjunction with a stability based program. The ability of strength training to prevent low back pain has not been demonstrated (Campello et al, 1996). However, there is some evidence from the literature that does show strength may provide a protective effect in low back pain when strength is needed for the task (Cady et al, 1979; Pheasant, 1991). This is logical because if the global muscle system is strained, excessive stress will be placed on the local muscle system and increases the likelihood of failure (Richardson et al, 1999a). It is essential that certain components of stability training be made the highest priority because strength training may be detrimental to healing pathology or motor recruitment dysfunction. Essential components involve controlling the neutral joint position and dissociation (relative flexibility). Slow motor unit recruitment also needs to be trained. Exactly when clients can start or integrate a strengthening program safely is individual and depends on a number of factors. It may involve the need for strength training, their initial level of stability, their ability to progress through stages and integrate them into

Stability dysfunction:

- **Is identified by the failure of the movement system under low load testing**

Strength dysfunction:

- **Is identified by the failure of the movement system under high load**

Figure 3: Identification of strength and stability dysfunction (From Comerford and Mottram, 2000, with permission).

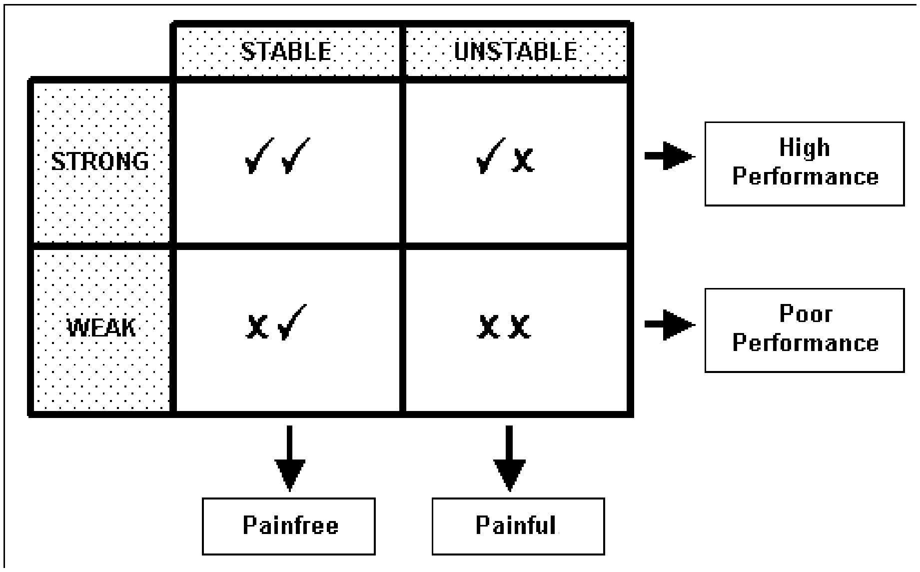

Figure 4: Functional outcomes from strength and stability assessments (From Comerford & Mottram, 2000, with permission).

function, level of proprioception and sensation of effort, dominant pain mechanism and beliefs about exercise.

Conclusion

Stability is a very different concept than strength and the terms are not synonymous. Strength is based on assessing muscle function with load while stability is assessing motor control regulation of muscle stiffness with no external load. Comerford (2000) proposed a different view of assessment (Figures 3 and 4). In a strength assessment, you pass or fail high load test (or are assessed with load) while in a stability assessment, you pass or fail a low load test (the load being limb load and movement).

It is possible to pass a strength test while still fail a stability test. The result may be high performance, but with pain and pathology. It is also possible to pass a stability test and do poorly on a strength assessment. The result is poor performance, but pain free and without pathology. When there is good strength and stability, the result is high performance and pain free. When there is poor stability and poor strength, the result is poor performance and with pain.

New understanding in muscle function is emerging based on sound anatomy, physiology, biomechanics and new concepts in stability. To date, there is debate as to whether strength training alone has been successful in treating low back pain in the long term (Dillingham and Delateur, 1995; Campello et al, 1996; David, 1997; Abenhaim et al, 2000). This paper has highlighted both benefits and limitations of strength training. In order to return to sport or return to work where strength is required, strength needs to be assessed and weakness identified. Strength and stability dysfunction should both be assessed and rehabilitated. 'Core stability' training is an integral part of training to tolerate activity with load (including sport) and should be used as part of an integrated strengthening program along with traditional strengthening programs and stability rehabilitation. The stability system comprises of local and global stability. It would likely be better, to rehabilitate both the local and global stability systems together. This could then be combined with a strengthening program. More research is needed in this field with controlled studies to determine the most effective rehabilitation protocols.

References

Abenhaim L, Rossignol M, Valat JP, Nordin M, Avouac B, Blotman F, Charlot J, Dreiser L, Legrand E, Rozenberg S and Vautravers P (2000) The role of activity in the therapeutic management of back pain. Report of the International Paris Task Force on Back Pain. Spine. 25 (4): 1S-33S

Bernardi M, Solomonow M, Nguyen G, Smith A and Baratta R (1996) Motor unit recruitment strategy changes with skill acquisition. European Journal of Applied Physiology. 74; 52-59

Brumagne S, Cordo, P, Lysens R, Verschueren S and Swinnen S (2000) The role of paraspinal muscle spindles in lumbosacral position sense in individuals with and without low back pain. Spine. 25 (8): 989-994

Burke RE (1968) Firing patterns of gastrocnemius motor units in the decerebrate cat. Journal of Physiology (London). 196: 631-634

Butler D (1991) Mobilisation of the Nervous System. Churchill Livingstone.

Cady LD, Bischoff DP, O'Connell ER, Thomas PC and Allan JH (1979) Strength and fitness and subsequent back injuries in fire fighters. Journal of Occupational Medicine. 21: 269-72

Caruso CM and Gill CD (1992) Strengthening physical self-perceptions through exercise. The Journal of Sports Medicine and Physical Fitness. 32: 416 27

Clarke J (1999) Muscle adaptation to function - recruitment, fibre type transformation and the clinical implications. Kinetic Control Newsletter. Vol 1: Issue 2. Internet site: www.kineticcontrol.com

Campello M, Nordin M and Weiser S (1996) Physical exercise and low back pain. Scandinavian Journal of Medicine & Science in Sports. 6: 63-72

Comerford M (2000) Movement and stability dysfunction - current evidence. Proceedings of: Y2K. Pain in the Neck. 12th Annual National Orthopaedic Symposium. Edmonton, Canada

Comerford M and Mottram S (2000) Movement Dysfunction: Focus on Dynamic Stability and Muscle Balance. Kinetic Control Movement Dysfunction Course Publication. Kinetic Control, Southampton.

Comerford M (2001) Stability Rehabilitation of Movement Dysfunction. Section 1: Theory and Concepts. Ch 3; p 12. Kinetic Control Movement Dysfunction Course Publication. Kinetic Control, Southampton.

David G (1997) Selection, training and ergonomics. Ergonomics and Musculoskeletal disorders (Module 5). MSc in Health Ergonomics. University of Surrey

Dillingham TR and Delateur BJ (1995) Exercise for low back pain: What really works? Spine: State of the Art Reviews. 9(3): 649-660

Dishman RK, Sallis JF, Orenstein DR (1985) The determinants of physical activity and exercise. Public health Rep. 100: 158-171

Elvey (1986) Treatment of arm pain associated with abnormal brachial plexus tension. The Australian Journal of Physiotherapy. 32 (4): 225-230

Gibbons SGT and Comerford MJ (2001) Strength versus stability: Part 1: Concepts and terms. Orthopaedic Division Review, March / April

Gifford L (1998) The "central" mechanisms. In: Gifford L. (Ed) Physiotherapy Pain Association Yearbook 1998-1999. Topical Issues in Pain. Whiplash - science and management. Fear avoidance beliefs and behaviour. CNS Press, Falmouth. p 67-80

Grimby L, Hannerz J (1976) Disturbances in voluntary recruitment order of low and high frequency motor units on blockades of proprioceptive afferent activity. Acta Physiologica Scandinavica 96: 207-216

Hakkinen K and Komi PV (1983) Electromyographic changes during strength training and detraining. Medicine and Science in Sports and Exercise. 15: 455-460

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

Howley ET (1976) The effect of different intensities of exercise on the excretion of epinephrine and norepinephrine. Medicine and Science in Sports. 8 (4): 219-222

Hupli M, Hurri H, Luoto S, Sainio P and Alaranta H 91996) Isokinetic performance capacity of trunk muscles. Part1: The effect of repetition on measurement of isokinetic performance capacity of trunk muscles among healthy controls and two different groups of low - back pain patients. Scand J Rehab Med. 28: 201-206

Janda V (1985) Pain in the locomotor system - A broad approach. In Glasgow et al. (eds.) Aspects of Manipulative Therapy. Churchill Livingstone: 148-151

Johansson H and Sojka P (1991) Pathophysiological mechanisms involved in genesis and spread of muscular tension in occupational muscle pain and chronic musculoskeletal pain syndromes: a hypothesis. Medical Hypothesis. 35: 196-203

Jones DA, Rutherford OM and Parker DF (1989) Physiological changes in skeletal muscle as a result of strength training. Quarterly Journal of Experimental Physiology. 74: 233-256

Lindstrom I, Ohlund C, Eek C, Wallin L, Peterson LE, Nachemson A (1992) Mobility, strength and fitness after a graded activity program for patients with subacute low back pain: A randomized prospective clinical study with a behavioral therapy approach. Spine. 17: 6. 641 - 652

Maier A, Eldred E and Edgerton VR (1972) The effects on spindles of muscle atrophy and hypertrophy. Experimental Neurology. 37: 100-123

McArdle WD, Katch FI and Katch VL (1996) Exercise Physiology 4th Ed. Williams & Wilkins, Baltimore

Mooney V (1995a) Why exercise for low back pain? The Journal of Musculoskeletal Medicine. Oct. 33-39

Mooney V (1995b) Treating low back pain with exercise. The Journal of Musculoskeletal Medicine. Dec. 24-36

Moritani T and DeVries HA (1979) Neural factors vs hypertrophy in time course of muscle strength gain. American Journal of Physical Medicine and Rehabilitation. 58: 115-130

Newton M, Somerville D, Henderson I and Waddell G (1993a) Trunk strength testing with iso-machines. Part 1: Review of a decade of scientific evidence. Spine. 18 (7): 801-811

Newton M, Somerville D, Henderson I and Waddell G (1993b) Trunk strength testing with iso-machines. Part 2: Experimental evaluation of the cybex II back testing system in normal subjects and patients with chronic low back pain. Spine. 18 (7): 812-824

Nicolaisen T and Jorgensen K 91985) Trunk strength, back muscle endurance and low back trouble. Scand Journal of Rehab Med. 17: 121-127

O'Sullivan PB, Twomey L, Allison G (1997) Evaluation of specific stabilising exercise in the treatment of chronic low back pain with radiological diagnosis of spondylosis or spondylolisthesis. Spine 22(24):2959-2967

Parkhurst TM and Burnett CN (1994) Injury and proprioception in the lower back. Journal of Orthopaedic and Sports Physical Therapy. 19: 5 283 - 295

Pheasant S (1991) Ergonomics, Work and Health. Macmillan, Houndmills

Pool-Goudzwaard AL, Vleeming A, Stoeckart R, Snijders CJ and Mens MA (1998) Insufficient lumbopelvic stability: a clinical, anatomical and biomechanical approach to 'a-specific' low back pain. Manual Therapy. 3 (1): 12-20

Revel M, Andre-Deshays C and Minguet (1991) Cervicocephalic kinesthetic sensibility in patients with cervical pain. Arch Phys Med Rehabil. 72: 288-291

Richardson C and Hodges P (1996) New advances in exercise to rehabilitate spinal stabilization. Edinburgh. Course Notes

Richardson CA, Jull GA (1995) Muscle control - pain control. What exercises would you prescribe? Manual Therapy. 1:1-9

Richardson C, Jull G, Hides J, Hodges P (1999a) Therapeutic Exercise for Spinal Stabilisation: Scientific basis and practical techniques. Churchill Livingstone London

Richardson C, Hides J and Roll S (1999b) Advanced instruction in retraining motor control for segmental stabilization: Including real-time ultrasound for feedback. London. Course Notes & Course Demonstration

Risch S, Norvell N, Pollock ML, Risch ED, Langer H, Fulton M, Graves JE, Leggett SC (1993) Lumbar strengthening in chronic low back pain: Physiologic and psychological benefits. Spine. 18 (2): 232-238

Rutherford OM and Jones DA (1986) The role of learning and co-ordination in strength training. European Journal of Applied Physiology. 55: 100-105

Sahrmann SA (2000) Diagnosis and Treatment of Movement Impairment Syndromes. Mosby, USA. In Press

Sahrmann SA (1992) Posture and muscle imbalance. Faulty lumbar-pelvic alignment and associated musculoskeletal pain syndromes. Orthopedic Division Review. Nov/Dec. 13-20

Sale DG (1988) Neural adaptation to resistance exercise. Medicine and Science in Sports and Exercise. 20 (5): S135-S145

Shacklock M (1995) Neurodynamics. Physiotherapy. 81 (1): 9-16

Stubbs M, Harris M, Solomonov M, Zhou B, Lu Y, Barrata RV (1998) Ligamento-muscular protective reflex in the lumbar spine of the feline. J Electromyogra Kinesiol. 8 (4): 197-204

Wagman IH, Pierce DS and Brugher RE (1965) Proprioceptive influences in volitional control of individual motor units. Nature (London). 207: 957-958

Watson P (2000) Psychosocial Predictors of Outcome From Low Back Pain. In: Gifford L (Ed) Physiotherapy Pain Association Yearbook 1999-2000. Topical Issues in Pain. Biopsychosocial assessment and management. Relationships and pain. CNS Press, Falmouth. p 85-109

Woolf CJ (1994) The dorsal horn: state dependent sensory processing and the generation of pain. In: Wall P and Melzack R (Eds) Textbook of Pain. 3rd Ed. Churchill Livingstone, Edinburgh. Ch 5, p101-112

Acknowledgment: The authors would like to kindly thank Kinetic Control for permission to reproduce Figures 3 (adapted) and 4.

Acknowledgment: The authors would like to kindly thank Kinetic Control for permission to reproduce Figures 3 (adapted) and 4.