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Chronic low back pain, core stability and Francis Bacon: implications for contemporary physiotherapy – a narrative review

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Abstract

Background: Chronic low back pain (LBP) is the most common cause of disability, hence multiple attempts have been undertaken to develop therapeutic strategies aimed at addressing the issue. The most commonly used strategies include motor control exercises of deep core muscles that stabilize the lower back. However, on the practical side, they require application of special devices, such as ultrasonography or electromyography as well as instructions and support provided by trained personnel. Despite the lack of high-quality empirical evidence, these exercises are extensively used in clinical practice.

Narrative Review: The vast body of literature collected suggests that the cause of chronic LBP should be sought in the structural and functional alterations within different levels of the central nervous system. These alterations and maladaptations apply to both the molecular and tissue levels. Nevertheless, successful treatment of these changes is currently possible due to an affordable, cognitive therapeutic approach. It encompasses a number of strategies that aim to restore the normal function of the nervous system using brain plasticity processes. These include graded motor imagery, mirror therapy, graded exposure, pain education, sensory training and pain coping strategies.

Conclusions: Lack of clear advantage in the application of the *core stability* exercises over other, potentially cheaper alternatives, implies a shift-paradigm from the existing bio-medical model of chronic LBP treatment towards modern cognitive approaches. As results of numerous studies confirm the validity of the approach aimed at restoring the structure and function of the central nervous system in contrast to the still common concept of treatment of the peripheral tissues of the body, more rigorous systematic reviews and meta-analysis are required. Evidence from this kind of evaluation may contribute to the shift in current beliefs regarding the treatment of chronic LBP.

Keywords: core stability; lumbar spine; chronic pain; transversus abdominis; cognitive-behavioral therapy; explain pain

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INTRODUCTION

As far back as the sixteenth century, the English philosopher Francis Bacon, advocated the introduction of scientific method in cognition a *status quo*. Nowadays, his thoughts and ideas continue to leave their mark on science understood in its broadest sense as well as on its individual fields, including medicine. His famous quote: *„We must not then add wings, but rather lead and ballast to the understanding, to prevent its jumping or flying"* perfectly reflects contemporary problems the scientific community is struggling with. Therefore, evidence based practice has been widely applied in recent years. Its assumptions refer to applying effective treatment strategies for currently burdensome health issues. Chronic pain, including chronic low back pain (LBP) is one of them, especially when considering its costs (Vos et al., 2012) and prevalence (Hoy et al., 2012) .

Indeed, chronic LBP still constitutes an unresolved issue. Although serious pathologies such as „red flags" or nerve root compressions have their equivalents in common diagnostic procedures (Henschke et al., 2009), still almost 85% of all cases refer to non-specific ailments (Waddell, 2004).This means that the determination of the exact patho-anatomical cause of emerging symptoms is often impossible (Dillingham, 1995; O'Sullivan, 2005). Another problem lies in the time-specific classification, by which acute LBP (lasting up to three months) is commonly associated with tissue damage, in chronic LBP this relation is not present (Apkarian et al., 2009).What are, then, the origins of chronic LBP?

According to the report published in *The Lancet*, chronic LBP is also a social problem (Vos et al., 2012). That syndrome have been ranked first among other 289 dysfunctions and diseases leading to disability (Vos et al., 2012). Furthermore, it has been estimated that the incidence of LBP in each consecutive year ranges from 6.3% to 15.4% in urban population (Hoy et al., 2010). In view of this data, finding effective therapeutic strategies, which could affect each group of patients reporting chronic LBP, is of crucial importance. One of such approaches contains motor control exercises of the trunk also known as *core stability* exercises (Vasseljen et al., 2012; Tsao and Hodges, 2007). According to different authors, performing this kind of exercises can contribute to reduction in pain intensity by improving motor control of the muscles surrounding the whole lumbo-pelvic-hip complex (Tsao and Hodges, 2007), by increasing its stiffness (Hodges et al., 2005) or by more effective transmission of forces from the trunk to both upper and lower extremities (Shinkle et al., 2012). Commonly, transversus abdominis (TrA) and the lumbar part of the multifidus muscle (MF) are trained. Despite extensive benefits from *core stability* exercises described in literature, their clinical value may be insufficient (Macedo et al., 2009).

This narrative review is an attempt at a critical evaluation of the most recent developments in non-operative treatment of chronic LBP sufferers by applying *core stability* exercise programme. In recent times this concept has gained prominence over both therapeutic and preventive aspects of medicine and also obscured the multidimensional biological and psycho-social approach to health-related studies (Engel, 1977). Still the empirical validity of the application of the *core stability* exercices in chronic LBP sufferers is, in fact, questionable. Finally, other non-invasive treatment approaches also fall within the scope of this work.

Bacon, and 'core stability'?

Francis Bacon regarded as the founder of empiricism, claimed that reality should be explored directly, i.e. experimentally – by applying the scientific method. Currently, this approach is widely used in the health-related sciences and known as evidence-based medicine (Sackett et al., 2007). However, its introduction met with some limitations and its nature has been aptly described by Bacon: *„There be that can pack the cards, and yet cannot play well"*. In this context, the concept of *core stability* and its variations require a more critical analysis. This perspective has led to a wealth of controversy regarding its areas of application.

Definitions, and „packing the card"

While it is difficult to determine the exact meaning of the term *'core stability'*, it is even more challenging to find evidence as to who coined it. The term in question is sometimes used to denote a large group of stabilization exercises, targeted at the *"core"* area (Key, 2012). According to Fig (2005), the anatomical location of the *„core"* is a body region located between the knee joints and sternum (Fig, 2005). Similarly, all the mechanisms based on bottom-up and top-down regulations (Schabrun et al., 2014) responsible for controlling the muscles and organs of this region and providing primary life functions should be considered an integral part of the *core*. This straightforward distinction between the structure and function, should be the basis for understanding how *core stability* exercises should be applied to reduce pain in patients with chronic LBP. Thus, considering only TrA and MF activity as *'core'* may be a biased perspective (see Lederman, 2010 for review).

Isolated strengthening of deep muscles surrounding the lumbar spine and pelvis in the case of LBP is not a new approach. As early as the first half of the twentieth century, Joseph Pilates emphasized the importance of the abdomen in his training strategy (Pilates and Miller, 1945). For many years there was no evidence that would convincingly explain why the abdominal muscles, especially those deeper-lying, should be included in the rehabilitation of patients with LBP. The turning point came with the quasi-axiom developed by a research group from Australia (Key,

[1] Bacon's Novum Organum (2nd Ed., 1878), 188; and this translated form can be found in Francis Bacon and James Spedding (trans.), The Works of Francis Bacon (1864), Vol. 8, 67.

2013), which assigned a crucial role to TrA - the deepest of all abdominal muscles. Those assumptions were derived from studies of TrA activity which showed that TrA was recruited significantly earlier than those muscles which directly performed the movement of either upper or lower limb (Hodges and Richardson, 1999b). Naturally, this evidence along with several reports of the delay in TrA activation in patients with LBP (Hodges and Richardson, 1999a) has become a driving force behind developing or enhancing a number of strategies and therapeutic methods such as Kinetic Control (Comerford and Mottram, 2001; Adamczyk et al., 2014), Neurac (Kirkesola, 2009; Vasseljen et al., 2012) or Proprioceptive Neuromuscular Facilitation (Lee et al., 2014).

According to Panjabi (1992), the lumbar spine without forces generated by muscle tissue is a potentially unstable system, which implies the need for the implementation of active rehabilitation when the muscular system is inefficient. One of the approaches recommended in literature includes exercises of the *core* area, i.e. TrA and MF, which aim to improve the stability of this region in chronic LBP patients. Sounding somewhat like a paradox, the question is vital: why should *core stability* be improved in chronic LBP sufferers if there is no strong evidence of tissue damage or structural body changes due to instability? And even if each case of chronic LBP was characterized by instability, the isolated training of only deep muscles should seem to be insufficient (Stokes et al., 2011; Gnat et al., 2013). Addressing this issue, a Canada-based research group has adopted a contrasting approach, which highlights the prominent role of more superficial muscles i.e. obliqus internus and externus abdominis and quadratus lumborum (McGill, 2002; Grenier and McGill, 2007; Brown and McGill, 2009) in the lumbar spine stability processes. The recommended way to train the *core*, as advocated by these authors, is to use a more global exercise, as opposed to the isolated Australian approach (McGill, 2002).

The Australian approach aroused, in fact, considerable controversy. The results of studies focused on TrA and MF feedforward activation seem to have attracted too much attention from clinicians and scientists (Allison and Morris, 2008). For example, the study conducted by Hodges and Richardson (1999b), which revealed that TrA is activated significantly earlier than other muscles responsible for movement performance - regardless of the type of motor task – was based on only 15 volunteers. It can be assumed that the statistical significance in this and other studies based on invasive measurement techniques can be related to the sample-size effect and/or inadequate sampling method. In another study, the same authors indicated that TrA is activated 50 ms after the contraction of the deltoid muscle (Hodges et al., 1999; Tokuno et al., 2013), involved in the execution of the upper limb movement. Lack of consistency between the reports implies that the validity of the *core stability* concept deserves to be reconsidered.

There is still another issue related to TrA training in patients with chronic LBP (Hodges and Richardson, 1999b). Vasseljen et al. (2012) have conducted extensive study whose aim was to verify the impact of *core stability* exercises on muscle recruitment time (Vasseljen et al., 2012) in patients suffering from chronic LBP. There was no evidence of a positive relationship between the activity of TrA, i.e. its activation time, and decreased pain levels (Vasseljen et al., 2012). Also, the claim that the impaired motor control of the *core* muscles is associated with worse prognosis (Ferreira et al., 2010a) seems problematic in view of a recent systematic review showing that based on the output data on TrA activity, the possibility of predicting the positive treatment outcomes is fairly limited (Wong et al., 2013). Therefore the question arises: what factors contribute to the decreased pain and disability levels in chronic LBP after intervention of *core stability* exercises in the clinical and research setting?

Cognitive approach or Bacon's „play well" rule

One of the most known Baconian considerations is called *idola mentis*, better known as idols of the human mind. According to Bacon, there are several groups of factors which may obstruct correct scientific reasoning. From the perspective of the *core stability* concept, the two most important obstacles seem to be "Idols of the Marketplace" and "Idols of the Cave". The former refers to imprecisely defined terms, which can be a source of misinterpretation (Reeves et al., 2007). The latter can be regarded as insufficient exploration of the available data.

So far, there is no evidence for the superiority of *core stability* regime over other types of exercises used in patients with chronic LBP (Macedo et al., 2010). Ferreira et al. (2010b) stated that there is one single effect on pain rates which refers to the „doses" of prescribed exercises where their type is not relevant. Subsequently, results of one randomized control trial have revealed lack of differences in outcomes with regard to reduction of pain and disability, in three groups of chronic LBP patients: one group followed a 10-week therapy based on *core stability* exercises, the second group was involved in cognitive therapy and the last one received combined treatment (Smeets et al., 2006). The post-treatment effect of reduced pain intensity in each group was maintained during one-year follow-up (Smeets et al., 2008). Other studies have shown that *core stability* exercises are not more effective than training programmes based on systematic walking (Smeets, 2009). Similar findings have been reported by other authors (Leeuw et al., 2008; Smeets et al., 2009) who also pointed out to the economic benefits of cognitive strategies. Indeed, in order to reliably carry out *core* muscle treatment, a number of more or less specialised devices such as ultrasonography (Koppenhaver et al., 2009), electromyography (McMeeken et al., 2004), or pressure biofeedback unit (Smeets, 2009) are necessary.

In turn, cognitive processes may explain the effectiveness of *core stability* exercises (Allison et al., 2008) observed in the clinical setting and in the case of those who suffer from the acute form of LBP (Allison et al., 2008). For example, a low score on FABQ (Fear Avoidance Beliefs Questionnaire), which indicates the absence of kinesiophobia, is associated with lower probability of positive patient response to the *core stability* exercise programme (Hicks et al., 2005). One cannot rule out the possibility that a person characterized by a low rate of kinesiophobia combined with extensive experience of physical activity (Knapik et al., 2014; Curtis et al., 1999) will not respond to the 'drawing in maneuver' since they simply will not believe in the effectiveness of such apparently trivial activity. This scenerio indicates that the placebo/nocebo effects may be involved in treatment outcomes (Benedetti and Amanzio, 2011; Benedetti, 2013). Conversely, a person with a kinesiophobic tendency might willingly accept such a marginal activity, which may correlate with the effectiveness of interventions.

„Human knowledge and human power meet in one"[1]

Data from a recent study published in *The Lancet* have revealed the actual impact of a therapy based on strengthening muscles - these being, however, not the muscles of the core region, but deep muscles of the cervical spine area (Michaleff et al., 2014). The study group consisted of patients suffering from chronic whiplash associated disorder (WAD). Although the *core* and the neck regions are distinct parts of the human body consisting of different muscles, therapeutic principles applicable in both cases are, in fact, quite similar. Over 170 patients were assigned to one of two groups, where patients in one group were advised to perform a set of *core stability* exercises for neck dysfunctions, while in the other only a single consultation was provided, during which the therapist discussed key factors that could have an impact on pain rate related to daily living activities, e.g. anxiety, fear, stress, etc. Surprisingly, a single consultation lasting for about 30 minutes returned exactly the same effects as those obtained following the 20-hour therapy sessions aimed at strengthening deep muscles of the neck (Michaleff et al., 2014).

„The brain in pain"

When analyzing the current state of knowledge about chronic LBP and chronic pain in general, it is not surprising that *core stability* exercises may not be effective, and even if they are, their effects seem to be not more significant than those obtained with a simple cognitive intervention. These results can be explained by the fact that pain and nociception are two distinct notions that are often confused. Pain is a sensory and emotional state that arises as the final output of the complex neuronal activity of the central nervous system (CNS) (Melzack, 2001, Butler and Moseley, 2003). In contrast, nociception is associated exclusively with conduction of sensory information on tissue damage to the CNS. The central nervous system 'decides' whether the body is endangered not only on the basis of nociception, but also taking into account individual beliefs about pain, thoughts, emotional feelings, etc. (Melzack, 2001). Therefore, pain may persist in the absence of structural correlates from the 'body' and without nociception.

Paradoxically, chronic LBP may be a consequence of structural alterations, but those originating from the CNS. The structural, neurochemical and functional changes have been observed within the CNS in patients with chronic LBP (Wand et al., 2011). The reduced levels of markers indicating the presence of activity of the dorsolateral prefrontal cortex (DLPFC), thalamus and orbitofrontal cortex are characteristic of chronic LBP (Grachev et al., 2000). Similarly, structural changes involving reduced density in gray matter within the DLPFC and thalamus (Apkarian et al., 2004), somatosensory cortex and brainstem (Schmidt-Wilcke et al., 2006) and posterior parietal cortex (Buckalew et al., 2008) have been noticed . Of particular interest seem to be alterations in the somatosensory cortex. Flor et al. (1997) demonstrated that in patients with chronic LBP, the area responsible for representing the 'back' is shifted towards the median plane and extended to the area responsible for recognition of the lower limb (Flor et al., 1997). Interestingly, the more prominent the shift, , the higher intensity of pain was reported by patients with chronic LBP (Lloyd et al., 2008).

Brain training

Currently, such treatment strategies are recommended for chronic LBP sufferers which focused on the restoration of alterations observed within the CNS (Moseley and Flor, 2012). Besides cognitive-behavioral therapies such as graded exposure to painful activity (Smeets et al., 2006; Smeets et al., 2008; Leeuw et al., 2008) graded motor imagery programme is also applicable (Moseley, 2006). This program consists of three stages during which the performance progresses gradually. Sessions within the first stage concentrate on the ability to distinguish between the left and right side of the body. Patients with chronic pain are unable to adequately perform this task, which may result from reorganization of the premotor cortex. Within the second stage patients imagine execution of movements which are usually painful or problematic (Wand et al., 2012). In the third stage mirror therapy is implemented where a mirror image of the healthy (not affected) part of the body and their movement helps to provide painless visual biofeedback and gradual regression of cortical

[1] Bacon's Novum Organum (2nd Ed., 1878), 188; and this translated form can be found in Francis Bacon and James Spedding (trans.), The Works of Francis Bacon (1864), Vol. 8, 67.

reorganization (Moseley et al., 2006; Moseley and Flor, 2012).

Application of pain education programme, for example "explain pain"(EP) also seems to be favorable (Butler and Moseley, 2003). This form of therapy was mentioned before in the context of WAD, yet it appears to be broadly applied in chronic LBP states. The objective of EP is to re-conceptualise beliefs about pain and attitudes towards it as well as understand the nature of pain and factors which may have an influence on its rate. A few studies have shown a positive effect of one-to-one EP sessions on reducing pain intensity (Moseley, 2002; Moseley, 2003; Ryan et al., 2010; Van Oosterwijck et al., 2011). Oher available methods of dealing with chronic LBP such as sensory training programmes (Flor et al., 2001) and pain coping strategies are discussed elsewhere (Peres and Lucchetti, 2010).

CONCLUSIONS

Bacon postulated that the world should be explored experimentally, which brings a number of practical implications, particularly relevant to health-related sciences. Given this, theories and therapeutic strategies of treating chronic LBP should be constantly reviewed and re-evaluated in order to apply the most appropriate solutions available, in terms of both effectiveness and socio-economic benefits.

Lack of superiority in the application of the *core stability* exercises in relation to other, potentially cheaper alternatives, implies a shift-paradigm from the existing bio-medical model of treating chronic LBP towards modern cognitive approaches. This tenet, previously claimed by Engel (1977) remains valid and requires more attention from those who manage chronic LBP patients. As numerous studies confirm the validity of the approach aimed at restoring the structure and functions of the central nervous system in contrast to the still common concept of treatment of the peripheral tissues of the body, there is an urgent need for more rigorous systematic reviews. Evidence from this kind of evaluation may induce an important change in current beliefs about the treatment of chronic LBP.

LITERATURE

1. Adamczyk W, Sobczak Z, Gryckiewicz S, Hadała M. Ocena braku kontroli wyprostu lędźwiowego odcinka kręgosłupa. Funkcjonalna ocena i terapia w oparciu o metodę Kinetic Control. Prakt Fizjoter Rehabil, 2013; 38: 12-17
2. Allison GT, Morris SL, Lay B. Feedforward responses of transversus abdominis are directionally specific and act asymmetrically: implications for core stability theories. J Orthop Sports Phys Ther, 2008; 38: 228-37
3. Allison GT, Morris SL. Transversus abdominis and core stability: has the pendulum swung? Brit J Sport Med, 2008; 42: 930-1
4. Apkarian AV, Baliki MN, Geha PY. Towards a theory of chronic pain. Prog Neurobiol, 2009; 87: 81-97
5. Apkarian AV, Sosa Y, Sonty S, Levy RM, Harden RN, Parrish TB, Gitelman DR. Chronic back pain is associated with decreased prefrontal and thalamic gray matter density. J Neurosci, 2004; 24: 10410-5
6. Benedetti F, Amanzio M. The placebo response: how words and rituals change the patient's brain. Patient Educ Couns, 2011; 84: 413-9
7. Benedetti F. Placebo and the new physiology of the doctor-patient relationship. Physiol Rev, 2013; 93: 1207-46
8. Brown S, McGill SM. Transmission of muscularly generated force and stiffness between layers of the rat abdominal wall. Spine, 2009; 34: 70-5
9. Buckalew N, Haut MW, Morrow L, Weiner D. Chronic pain is associated with brain volume loss in older adults: preliminary evidence. Pain Med, 2008; 9: 240-8
10. Butler D, Moseley GL. Explain Pain. Adelaide, Australia: NOI Group Publishing; 2003
11. Comerford MJ, Mottram SL. Movement and stability dysfunction—contemporary developments. Man Ther, 2001; 6: 15-26
12. Curtis J, McTeer W, White P. Exploring effects of school sport experiences on sport participacion in later life. Sociol Sport J, 1999;16: 348-65
13. Dillingham T. Evaluation and management of low back pain: andoverview. State of the Art Reviews, 1995; 9: 559–74
14. Engel GL. The need for a new medical model: a challenge for biomedicine. Science, 1977; 196: 129-136
15. Ferreira ML, Smeets RJ, Kamper SJ, Ferreira PH, Machado LA. Can we explain heterogeneity among randomized clinical trials of exercise for chronic back pain? A meta-regression analysis of randomized controlled trials. Phys Ther, 2010b; 90: 1383-403
16. Ferreira PH, Ferreira ML, Maher CG, Refshauge K, Herbert RD, Hodges PW. Changes in recruitment of transversus abdominis correlate with disability in people with chronic low back pain. Brit J Sport Med, 2010a; 44: 1166-72
17. Fig G. Sport-specific conditioning: strength training for swimmers – training the core. Strength Cond J, 2005; 27: 40-1

18. Flor H, Braun C, Elbert T, Birbaumer N. Extensive reorganization of primary somatosensory cortex in chronic back pain patients. Neurosci Lett, 1997; 224: 5-8
19. Flor H, Denke C, Schäfer M, Grüsser S. Effect of sensory discrimination training on cortical reorganisation and phantom limb pain. Lancet, 2001; 357: 1763-4
20. Gnat R, Spoor K, Pool-Goudzwaard A. Simulated transversus abdominis muscle force does not increase stiffness of the pubic symphysis and innominate bone: an in vitro study. Clin Biomech, 2013; 28: 262-7
21. Grachev ID, Fredrickson BE, Apkarian AV. Abnormal brain chemistry in chronic back pain: an in vivo proton magnetic resonance spectroscopy study. Pain, 2000; 89: 7-18
22. Grenier SG, McGill SM. Quantification of lumbar stability by using 2 different abdominal activation strategies. Arch Phys Med Rehab, 2007; 88: 54-62
23. Henschke N, Maher CG, Refshauge KM, Herbert RD, Cumming RG, Bleasel J, York J Das A, McAuley JH. Prevalence of and screening for serious spinal pathology in patients presenting to primary care settings with acute low back pain. Arthritis Rheum, 2009; 60: 3072-80
24. Hicks GE, Fritz JM, Delitto A, McGill SM. Preliminary development of a clinical prediction rule for determining which patients with low back pain will respond to a stabilization exercise program. Arch Phys Med Rehab, 2005; 86: 1753-62
25. Hodges P, Cresswell A, Thorstensson A. Preparatory trunk motion accompanied rapid upper limb movement. Exp Brain Res, 1999; 124: 69–79
26. Hodges PW, Eriksson AE, Shirley D, Gandevia SC. Intra-abdominal pressure increases stiffness of the lumbar spine. J Biomech, 2005; 38: 1873-80
27. Hodges PW, Richardson CA. Altered trunk muscle recruitment in people with low back pain with upper limb movement at different speeds. Arch Phys Med Rehabil, 1999a; 80: 1005-12
28. Hodges PW, Richardson CA. Transversus abdominis and the superficial abdominal muscles are controlled independently in a postural task. Neurosci Lett, 1999b; 265: 91-4
29. Hoy D, Brooks P, Blyth F, Buchbinder R. The Epidemiology of low back pain. Best Pract Res Cl Rh, 2010; 24: 769-81
30. Key J. 'The core': understanding it, and retraining its dysfunction. J Bodyw Mov Ther, 2013; 17: 541-59
31. Kirkesola G. Neurac – a new treatment method for chronic musculosekeltal pain. Fysioterapeuten, 2009; 76: 16-25
32. Knapik A, Saulicz E, Rottermund J, Saulicz M, Myśliwiec A, Linek P. Einfluss von Leistungssport auf die Beweglichkeit in späteren Lebensjahren. Deut Z Sportmed, 2014; 65: 16-21
33. Koppenhaver SL, Hebert JJ, Fritz JM, Parent EC, Teyhen DS, Maqel JS. Reliability of rehabilitative ultrasound imaging of the transversus abdominis and lumbar multifidus muscles. Arch Phys Med Rehabil, 2009; 90: 87-94
34. Lederman E. The myth of core stability. J Bodyw Mov Ther, 2010; 1: 84-98
35. Lee CW, Hwangbo K, Lee IS. The Effects of Combination Patterns of Proprioceptive Neuromuscular Facilitation and Ball Exercise on Pain and Muscle Activity of Chronic Low Back Pain Patients. J Phys Ther Sci, 2014; 26: 93–96
36. Leeuw M, Goossens ME, van Breukelen GJ, de Jong JR, Heuts PH, Smeets RJ, Köke AJ, Vlaeyen JW. Exposure in vivo versus operant graded activity in chronic low back pain patients: results of a randomized controlled trial. Pain, 2008; 138: 192-207
37. Lloyd D, Findlay G, Roberts N, Nurmikko T. Differences in low back pain behavior are reflected in the cerebral response to tactile stimulation of the lower back. Spine, 2008; 33: 1372-7
38. Macedo LG, Maher CG, Latimer J, McAuley JH. Motor control exercise for persistent, nonspecific low back pain: a systematic review. Phys Ther, 2009; 89: 9-25
39. Macedo LG, Smeets RJ, Maher CG, Latimer J, McAuley JH. Graded activity and graded exposure for persistent nonspecific low back pain: a systematic review. Phys Ther, 2010; 90: 860-79
40. McGill S,. Low Back Disorder: Evidence-Based Prevention and Rehabilitation. Champaign, IL: Human Kinetics, 2002
41. McMeeken JM, Beith ID, Newham DJ, Milligan P, Critchley DJ. The relationship between EMG and change in thickness of transversus abdominis. Clin Biomech, 2004; 19: 337-42
42. Melzack R. Pain and the neuromatrix in the brain. J Dent Educ, 2001; 65: 1378-82
43. Michaleff ZA, Maher CG, Lin CW, Rebbeck T, Jull G, Latimer J, Connelly L, Sterling M. Comprehensive physiotherapy exercise programme or advice for chronic whiplash (PROMISE): a pragmatic randomised controlled trial. Lancet, 2014; 384: 133-41
44. Moseley GL, Flor H. Targeting cortical representations in the treatment of chronic pain: a review. Neurorehab Neural Re, 2012; 26: 646-52
45. Moseley GL. Graded motor imagery for pathologic pain: a randomized controlled trial. Neurology, 2006; 67: 2129-34

46. Moseley GL. Joining forces—combining cognition-targeted motor control training with group or individual pain physiology education: a successful treatment for chronic low back pain. J Manip Physiol Ther, 2003; 11: 88-94
47. Moseley L. Combined physiotherapy and education is efficacious for chronic low back pain. Aust J Physiother, 2002; 48: 297-302
48. O'Sullivan P. Diagnosis and classification of chronic low back pain disorders: Maladaptive movement and motor control impairments as underlying mechanism. Man Ther, 2005; 10: 242–55
49. Peres MF, Lucchetti G. Coping strategies in chronic pain. Curr Pain Headache Rep, 2010; 14: 331-8
50. Pilates, JH, Miller, WJ. Pilate's Return to Life through Contrology. Presentation Dynamics Inc, 1945
51. Reeves NP, Narendra KS, Cholewicki J. Spine stability: the six blind men and the elephant. Clin Biomech, 2007; 22: 266-74
52. Ryan CG, Gray HG, Newton M, Granat MH. Pain biology education and exercise classes compared to pain biology education alone for individuals with chronic low back pain: a pilot randomised controlled trial. Man Ther, 2010; 15: 382-7
53. Sackett DL, Rosenberg WM, Gray JA, Haynes RB, Richardson WS. Evidence based medicine: what it is and what it isn't. 1996. Clin Orthop Relat Res, 2007; 455: 3-5
54. Schabrun SM, Jones E, Elgueta Cancino EL, Hodges PW. Targeting chronic recurrent low back pain from the top-down and the bottom-up: a combined transcranial direct current stimulation and peripheral electrical stimulation intervention. Brain Stimul, 2014; 7: 451-9
55. Schmidt-Wilcke T, Leinisch E, Ganssbauer S, Draganski B, BogdahnU, Altmeppen J, May A. Affective components and intensity of pain correlate with structural differences in gray matter in chronic back pain patients. Pain, 2006; 125: 89-97
56. Shinkle J, Nesser TW, Demchak TJ, McMannus DM. Effect of core strength on the measure of power in the extremities. J Strength Cond Res, 2012; 26: 373-80
57. Smeets RJ, Severens JL, Beelen S, Vlaeyen JW, Knottnerus JA. More is not always better: cost-effectiveness analysis of combined, single behavioral and single physical rehabilitation programs for chronic low back pain. Eur J Pain, 2009; 13: 71-81
58. Smeets RJ, Vlaeyen JW, Hidding A, Kester AD, van der Heijden GJ, van Geel AC, Knottnerus JA. Active rehabilitation for chronic low back pain: cognitive-behavioral, physical, or both? First direct post-treatment results from a randomized controlled trial [ISRCTN22714229]. BMC Musculoskelet Disord, 2006; 7: 5
59. Smeets RJ, Vlaeyen JW, Hidding A, Kester AD, van der Heijden GJ, Knottnerus JA. Chronic low back pain: physical training, graded activity with problem solving training, or both? The one-year post-treatment results of a randomized controlled trial. Pain, 2008; 134: 263-76
60. Smeets RJ. Do lumbar stabilising exercises reduce pain and disability in patients with recurrent low back pain? Aust J Physiother, 2009; 55: 138
61. Stokes IA, Gardner-Morse MG, Henry SM. Abdominal muscle activation increases lumbar spinal stability: analysis of contributions of different muscle groups. Clin Biomech, 2011; 26: 797-803
62. Tokuno CD, Cresswell AG, Thorstensson A, Carpenter MG. Recruitment order of the abdominal muscles varies with postural task. Scand J Med Sci Spor, 2013; 23: 349-54
63. Tsao H, Hodges PW. Immediate changes in feedforward postural adjustments following voluntary motor training. Exp Brain Res, 2007; 181: 537-46
64. Van Oosterwijck J, Nijs J, Meeus M, Truijen S, Craps J, Van den Keybus N, Paul L. Pain neurophysiology education improves cognitions, pain thresholds, and movement performance in people with chronic whiplash: a pilot study. J Rehabil Res Dev, 2011; 48: 43-8
65. Vasseljen O, Unsgaard-Tøndel M, Westad C, Mork PJ. Effect of core stability exercises on feed-forward activation of deep abdominal muscles in chronic low back pain: a randomized controlled trial. Spine, 2012; 37: 1101-8
66. Vos T, Flaxman AD, Naghavi M, Lozano R, Michaud C et al. Years lived with disability (YLDs) for 1160 sequelae of289 diseases and injuries 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. Lancet, 2012; 380: 2163-96
67. Waddell G. The Back Pain Revolution. Churchill Livingstone: Edinburgh 2004
68. Wand BM, Parkitny L, O'Connell NE, Luomajoki H, McAuley JH, Thacker M, Moseley GL. Cortical changes in chronic low back pain: Current state of the art and implications for clinical practice. Man Ther, 2011; 16: 15-20
69. Wand BM, Tulloch VM, George PJ, Smith AJ, Goucke R, O'Connell NE, Moseley GL. Seeing it helps: movement-related back pain is reduced by visualization of the back during movement. Clin J Pain, 2012; 28: 602-8
70. Wong AY, Parent EC, Funabashi M, Stanton TR, Kawchuk GN. Do various baseline characteristics of transversus abdominis and lumbar multifidus predict clinical outcomes in nonspecific low back pain? A systematic review. Pain, 2013; 154: 2589-602