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The Evidence of Physical Activity and Training for the Therapy of Chronic Non-Specific Back Pain

Die Evidenz von körperlicher Aktivität und Training zur Therapie chronisch unspezifischer Rückenbeschwerden

REVIEW

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Summary

- **Problem:** Physical activity has an enormous relevance for the treatment of back pain (BP) in the clinical field. This paper gives a brief overview of the evidence of physical activity for the treatment of chronic back pain and summarizes the current approach of the German national project Medicine in Spine Exercise (MiSpEx: sensorimotor training (SMT) with perturbation).
- **Methods:** 35 literature reviews were screened for inclusion criteria concerning physical activity for the treatment of cBP. Of these, 16 systematic reviews and 2 guidelines were included following the criteria: systematic review in English, evaluating pain and disability in the context of physical activity for the treatment of back pain, published 2000-2017 and considering less than a third of RCTs without a subclassification of patients. We did not conduct a quantitative meta-analysis but a qualitative synthesis.
- **Results:** Exercise Therapy reduces pain and disability in cBP patients but there is still no evidence that any one specific approach is the most favorable. Motor control exercises (MCE) seem to improve outcomes best, but SMT was mostly unconsidered.
- **Conclusion:** SMT further improves motor control by training the adjustment to unexpected stimuli in complex tasks considering both: afferent and efferent workloads. Furthermore, additional perturbation may improve sensorimotor adaptations through higher demands on core stability and increase the precise stabilizing feedback in cBP patients.

KEY WORDS:
Exercise Therapy, Chronic Back Pain, Sensorimotor Training, Proprioception

Zusammenfassung

- **Problem:** Patienten mit subakuten und chronischen nicht-spezifischen Rückenbeschwerden (RB) profitieren im Allgemeinen von einer Bewegungstherapie. Diese Publikation gibt einen Überblick über die Evidenz körperlicher Aktivität für die Therapie chronischer RB und begründet damit den Forschungsansatz des aktuellen Projekts des deutschen Forschungsnetzwerks MiSpEx (sensomotorische Intervention inkl. Perturbation) vor.
- **Methodik:** Es wurden 35 international veröffentlichte Reviews zur Wirksamkeit körperlicher Aktivität als Therapeutikum bei chronischen RB berücksichtigt sowie 16 systematische Reviews und 2 Richtlinien in die endgültige Analyse nach folgenden Kriterien aufgenommen: systematische Reviews in englischer Sprache mit den Outcomes Schmerz und Einschränkungen im Kontext physischer Aktivität für die Behandlung von Rückenschmerz, publiziert zwischen 2000-2017, die weniger als ein Drittel RCTs ohne Subklassifizierung der Patienten integrierten. Die Daten wurden rein qualitativ zusammengeführt, d.h. es erfolgte keine quantitative Metaanalyse.
- **Ergebnisse:** Bewegungstherapie verringert nachweislich den Schmerz und die funktionellen Beeinträchtigungen bei Patienten mit chronischen RB. Aktuell existiert keine Evidenz, die einer speziellen Trainingsmethodik Präferenz einräumt, es gibt aber Hinweise, dass ein Training der motorischen Kontrolle den größten Effekt auf den Therapieerfolg hat. Diesbezüglich finden sich allerdings bislang nur wenige Studien, die das spezielle sensomotorische Training berücksichtigen.
- **Fazit:** Sensomotorisches Training, welches die motorische Kontrolle und damit die Reaktion auf unerwartete Störreize trainiert, ist eine vielversprechende Form der Bewegungstherapie bei Patienten mit chronischen RB. Additive Perturbationen scheinen durch die erhöhte Beanspruchung der posturalen Kontrolle, zusätzliche positive Effekte auf die Feedbackkontrolle der stabilisierenden Strukturen aufzuweisen.

SCHLÜSSELWÖRTER:
Bewegungstherapie, chronische Rückenschmerzen, sensomotorisches Training, Propriozeption

Introduction, Problems and Objectives

Muscle strength, endurance and neuromuscular coordination have been shown to be related to cBP as their dysfunctions decreases spinal stability (7, 22, 34, 61, 65). Several authors have reported a lower level of activity and muscle atrophy for cBP patients (cBPP) (6, 20, 71, 76), whereby especially the motor control of the lumbar region is decreased (70). Additionally, a less refined proprioception in cBPP as a sensorimotor dysfunction has been found disturbing the precise stabilizing feedback control (37, 60, 62) and therefore probably leading to changes in postural control (14, 26, 37, 56). This maladaptation may eventually lead to relevant programming changes in the central nervous system (CNS) in cBPP (35, 37, 59). ›

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Table 1

Characteristics of studies included in the systematic review.

AUTHOR	YEAR	TYPE	RESULTS
Hartigan et al. [47]	2018 (under Rev.)	Review	Exercise prevents recurrence of BP
			Exercise Therapy with pain and disability reduction in subacute and cBPP
Kinser et al. [48]	2017	Review	Gentle physical activity and yoga-based interventions recommended for LBP patients (LBPP) and related symptoms
Gordon & Bloxham [49]	2016	Review	Combination of different approaches are most promising for BP Therapy
Saragiotto et al. [21]	2016	Review	MCE superior in pain and disability short- to midterm vs passive therapy
			No significant differences between MCE and other Exercise Therapy
Searle et al. [50]	2015	Review	Strength/Resistance training with small significant effect on pain
			Beneficial effect for strength/resistance and coordination/stabilization treatments over other Exercise Therapies
van Middelkoop et al. [51]	2010	Review	Exercise effective for pain and disability
			No Exercise more effective than another
			Small effects overall
Yue et al. [52]	2014	Review	Sling Exercise not superior to any other Exercise Therapy
Macedo et al. [53]	2013	Review	Less reoccurrence of BP through Exercise Therapy
van Middelkoop et al. [54]	2011	Review	Exercise therapy improved pain intensity and disability and long-term function compared to usual care
Bigos et al. [55]	2009	Review	Some Exercise interventions effective, others not
			Exercise approaches benefits beyond their intended physiologic goals
Macedo et al. [25]	2009	Review	MCE superior to minimal intervention
			Not more effective than other Exercise Therapy
			Reduces Pain and Disability
Keller et al. [56]	2007	Review	Exercise therapy with modest effect sizes for chronic LBP patients (cLBPP) compared to non-treatment controls
Chou et al. [57]	2007	Guideline USA	First-line for chronic LBP (cLBP): Exercise therapy and others like rehabilitation, acupuncture, massage, spinal manipulation and cognitive-behavioral therapy recommended
Airaksinen et al. [19]	2006	Guideline EUR	Supervised exercise therapy – beside other treatments – recommended for cLBP
			First-line treatment BP: For cLBP Exercise therapy superior over surgeries, medication or passive treatments
Hayden et al. [58]	2005	Review	Individual Exercise therapy (strengthening and stretching) with supervision improves pain and function in cLBP patients
			Adherence strategies important
Rainville et al. [59]	2004	Review	Improvements in pain ratings and disability due to Exercise Therapy
			Exercise Therapy effective vs. impairments in back flexibility and strength
Liddle et al. [60]	2004	Review	Exercise (strengthening and stretching) with positive and in follow-up maintaining effects in cLBP patients
			Co-interventions important
van Tulder et al. [61]	2000	Review	Exercise therapy more effective in cLBP patients than usual care
			Conflicting evidence that strengthening exercises more effective than inactive treatment for cLBP
			Specific back exercises with no clinical effect

Exercise therapy is the first-line treatment according to the European Guidelines for the Management of chronic non-specific BP (cnBP) (1). Its overall aim is to reduce BP via specific exercises to lead cBPP towards a higher loading capacity, a recovery of resilience for (occupational) activities of daily living and a reduction of fear avoidance behavior (8, 58). Thereby, physical activity (PA) not only leads to morphologic, e.g. muscle hypertrophy, flexibility (range of motion) and posture as well as neuronal (inter- and intramuscular) adaptations (10) but is also able to enhance psychosocial well-being as it may reduce stress, anxiety, and depression and improve self-esteem as well as the quality of life (16).

Strengthening exercise and segmental stabilization have been found to reduce pain and functional disability (24). Through a recalibration or normalization of physical activity (PA), a reduction of pain experience and its threshold may be reached even better than medically (4, 38). Basic muscle strength reflects the foundation of every other training phase and can be reached either by hypertrophy or neuronal adaptation. In conclusion, proper training stimuli lead to the optimal physiological performance achieved through neuronal adaptation, followed by hypertrophy (10, 12).

The focus of exercise therapy in back pain patients in recent years has been lying on core stability with specific training

exercises for deep trunk muscles (e.g. Transversus Abdominis and Quadratus Lumborum) to provide a fine motor and postural control, muscle coordination and static as well as dynamic stability (7, 58, 66, 67).

However, certain literature reviews suggest that no exercise is favorable to another (5, 15, 17, 30, 50, 53, 77). Moreover, exercise interventions are not evaluated thoroughly regarding either the neuronal system with neurophysiologic reorganization as important component of cBP treatment (3,11,25,36,67,80) or the dose-response relationship.

SMT (47, 67) seems to be promising as it not only improves core stability, postural control and pain alleviation but optimizes proprioception and neuromuscular coordination leading to an adaptation of cortical reorganization (3, 11, 25, 67). SMT (neuromuscular or proprioceptive training) is highly recommended for cBPP (54, 59) as it "emphasizes postural control and progressive challenges to the sensorimotor system to restore normal motor programs" (59).

It aims at stimulating the proprioceptors for improving muscle response and endurance in dynamic environments, and therefore trains how well a system adapts to changing requirements (feedback control). External perturbation training triggers automatic postural responses to maintain stability even in complex situations (60) with rising uncertainties and disturbances (66) improving the afferent and efferent processes in time and efficiency (14, 19, 33, 46, 55, 59, 63, 72). Ultimately, SMT thereby modifies the afferent input on the CNS (10) in cBPP especially of the injured or painful back muscle region as on unstable surfaces less reliable ankle joint proprioception is downweight and proximal proprioception is upweight. A change in these patterns (cortical reorganization) may decrease pain (recurrence), disability and increase fine postural control variability (3, 14). Additionally, through the perturbations in SMT, the participant focuses consciously on a non-painful stimulus which may help to revalue chronic pain (21, 69).

In total, through the destabilizing surfaces, additional perturbations and variable nature of SMT, it is highly efficient on (neuromuscular) functional performance, and pain reduction (36). Therefore, the aim of this short overview is to summarize recent reviews about the evidence of physical activity for the treatment of cnBP regarding training method and dose-response.

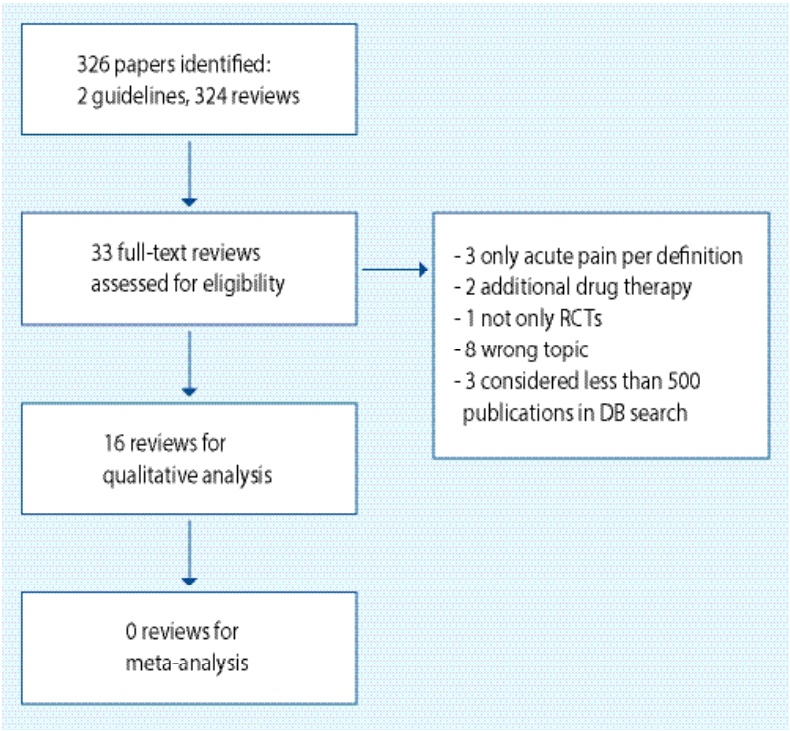

Figure 1

Work-flow diagram of the review process.

Methods

This review is based on a literature research including international reviews covering the key words 'systematic review', 'physical activity', 'exercise therapy' and 'chronic back pain'. Thus, we performed an electronic search for relevant articles in the following databases (English language): Cochrane Database, Pubmed, MedLine and SPOFOR (01/2000-10/2017). Two authors independently searched for potentially relevant titles and abstracts based on the specified criteria. Disagreements were solved by a third independent reviewer.

From 326 identified publications regarding our search criteria, 243 were eliminated concerning their topic (non-/invasive/physiotherapeutic treatments, drug use, different disease, acute trauma, economic view or psychological approach) and additional 48 duplicates were removed, leading to 35 full-text articles assessed for eligibility (Fig.1). The literature reviews were screened and we ended up with 16 systematic reviews matching our inclusion criteria (Tab. 1):

- Systematic reviews (Cochrane guidelines)
- Evaluating risk of bias
- Definition of the investigated intervention
- Topic of physical activity as a treatment of chronic non-specific back pain
- Published: 2000-2017
- Evaluating the outcomes: pain and disability
- Including less than 33% of RCT without a subclassification of patients

We additionally included 2 Guidelines for the treatment of back pain (European & American) to consider the current state of the art.

Due to the limited data, missing homogenous subclassification of patients and diverse definitions of back pain we did not conduct a quantitative meta-analysis but only a qualitative synthesis.

Results

In reviewing the literature, low to moderate evidence was found on the effect of physical activity as a treatment for cLBP in terms of pain and disability reduction. Several authors recapitulate that neither general nor specific approaches are preferable but the combination of different methods of training (27, 31, 32, 49, 75).

All exercise therapies MCE (67), Pilates (44, 45), Yoga (79), Stretching (40), Whole-body vibration training (39), proprioceptive neuromuscular facilitation (PNF) (2, 42), aerobic exercise and resistance training (1) have been shown to reduce pain and disability as well as to prevent BP reoccurrence being superior over no exercises in cBP. Nevertheless, there is still no evidence of one treatment superior to another in cnBP patients (cnBPP). ›

A major problem in studies dealing with the topic of exercise therapy seems to be the integration of subclassification strategies. Out of 68 investigations, less than 8% subclassified patients beyond inclusion and exclusion criteria, leading to low quality research (23). Additionally, most RCTs not only lack in clear description and standardization of the intervention applied, but are planned as short- to midterm investigations. Thus, no review was able to give evidence based advices regarding to training specific parameters, especially in the long-term.

Conclusion

This paper set out with the aim of assessing the importance of physical activity for the treatment of chronic back pain. Based upon an overview of current reviews dedicated to the effects of different exercise approaches, it further supports the idea of physical training as first line therapy. Although, no exercise seems favorable to another, it appears that MCE seem to be most promising in the field of short- to midterm reduction in pain and disability. Precise voluntary/efferent stimuli thus may enhance control and coordination of deep and global trunk muscles to reduce pain and disability.

Surprisingly, the concept of sensorimotor exercises has not previously been described in a systematic literature review, even though it proves to enhance neuromuscular performance, especially in dynamic environments. Considering afferent and efferent workloads, SMT further improves motor control by training the adjustment to unexpected stimuli at complex tasks. These ideas match those observed in the MiSpEx studies and suggest that SMT is able to produce superior outcomes compared to simple MCE. Additionally, current research evaluates possible secondary effects of additional perturbations during SMT for BPP. It is hypothesized that sensorimotor adaptations to motor control can be improved decisively through higher demands on core stability.

Training Advice

Several reports have shown that no exercise therapy is favorable to another for the treatment of cBP, although it must be mentioned that very little was found in the literature on the question of SMT effectiveness and effect size. Additionally, existing studies and reviews have inconsistently noted methods of SMT to achieve neuromuscular adaptations.

Generally, the World Health Organization (WHO) advises "muscle-strengthening activities [...] on 2 or more days a week" (78) for adults aged 18 to 65, reflecting rather a minimal (muscle maintenance) than an optimal (muscle enhancement) recommendation (29). A positive impact of SMT in such frequency has already been shown for a German cnBP population by the MiSpEx research network (52). Therefore, taking several studies into account, it appears that 2 to 3 times SMT per week over a period of 12 weeks seems to be a promising frequency of exercise for the treatment of cnBP.

Saragiotto et al. (67) advice that future investigations and interventions need to include a precise description of the exercises, an adequate sample size, significant long-term results, a different perspective on responders/non-responders and an economic perspective as well (67). Considering the MiSpEx setup since 2013, including over 34 studies with an overall sample size of >2000, moderating factors within the psychosocial context, a follow-up period of 1 year and developing a transfer concept for the health care system, it covers all aspects to add to the current state of research.

Förderung

Das MiSpEx-Netzwerk wird gefördert aus Mitteln des Bundesinstituts für Sportwissenschaft (BiSp) aufgrund eines Beschlusses des Deutschen Bundestages [Förderkennzeichen ZMVI1-080102A/11-18].

References

(1) **AIRAKSINEN O, BROX JI, CEDRASCHI C, HILDEBRANDT J, KLABER-MOFFETT J, KOVACS F, MANNION AF, REIS S, STAAL JB, URSIN H, ZANOLI G.** Chapter 4. European guidelines for the management of chronic nonspecific low back pain. Eur Spine J. 2006; 15: s192-s300. doi:10.1007/s00586-006-1072-1

(2) **AREEUDOMWONG P, WONGRAT W, NEAMMESRI N, THONGSAKUL T.** A randomized controlled trial on the long-term effects of proprioceptive neuromuscular facilitation training, on pain-related outcomes and back muscle activity, in patients with chronic low back pain. Musculoskelet Care. 2017; 15: 218-229. doi:10.1002/msc.1165

(3) **BAE SH, HWANG JA, KIM HJ.** The Effects of Sensorimotor Training Applied to Chronic Low Back Pain Patients on Their Pain and Change in Excitability of Cerebral Cortex Neurons. International Journal of Bio-Science and Bio-Technology. 2014; 6: 33-44. doi:10.14257/ijbsbt.2014.6.4.04

(4) **BAIAMONTE BA, KRAEMER RR, CHABRECK CN, REYNOLDS ML, MCCALEB KM, SHAHEEN GL, HOLLANDER DB.** Exercise-induced hypoalgesia: Pain tolerance, preference and tolerance for exercise intensity, and physiological correlates following dynamic circuit resistance exercise. J Sports Sci. 2017; 35: 1831-1837. doi:10.1080/02640414.2016.1239833

(5) **BALAGUÉ F, MANNION AF, PELLISE F, CEDRASCHI C.** Non-specific low back pain. Lancet. 2012; 379: 482-491. doi:10.1016/S0140-6736(11)60610-7

(6) **BARKER KL, SHAMLEY DR, JACKSON D.** Changes in the cross-sectional area of multifidus and psoas in patients with unilateral back pain: the relationship to pain and disability. Spine. 2004; 29: E515-E519. doi:10.1097/01.brs.0000144405.11661.eb

(7) **BARON EM, TUNSTALL R.** The back. In: Standring S, ed. Gray's Anatomy Vol 41st. Edinburgh: Elsevier Churchill Livingstone; 2016: 710-773.

(8) **BIGOS SJ, HOLLAND J, HOLLAND C, WEBSTER JS, BATTIE M, MALMGREN JA.** High-quality controlled trials on preventing episodes of back problems: systematic literature review in working-age adults. Spine J. 2009; 9: 147-168. doi:10.1016/j.spinee.2008.11.001

(9) **BISP.** Beobachtungen und Erkenntnisse aus der 1. Projektphase. 2017. http://www.ranruecken.de/Ruecken/DE/Projektnews/Erkenntnisse/erkenntnisse_node.html [16th September 2017].

(10) **BOMPA T, BUZZICHELLI C.** Periodization Training for Sports-3rd Edition. 2015; Human Kinetics Publishers.

(11) **BORGHUIS J, HOF AL, LEMMINK KA.** The importance of sensory-motor control in providing core stability: implications for measurement and training. Sports Med. 2008; 38: 893-916. doi:10.2165/00007256-200838110-00002

(12) **BRINCKMANN P, FROBIN W, LEIVSETH G, DRERUP B.** Orthopädische Biomechanik (Vol. Reihe V). Münster, Germany. 2012; Universitäts- und Landesbibliothek Münster.

(13) **BRUHN S, KULLMANN N, GOLLHOFER A.** The effects of a sensorimotor training and a strength training on postural stabilisation, maximum isometric contraction and jump performance. Int J Sports Med. 2004; 25: 56-60. doi:10.1055/s-2003-45228

(14) **BRUMAGNE S, JANSSENS L, KNAPEN S, CLAEYS K, SUUDEN-JOHANSON E.** Persons with recurrent low back pain exhibit a rigid postural control strategy. Eur Spine J. 2008; 17: 1177-1184. doi:10.1007/s00586-008-0709-7

(15) **BYSTRÖM MG, RASMUSSEN-BARR E, GROOTEN WJ.** Motor control exercises reduces pain and disability in chronic and recurrent low back pain: a meta-analysis. Spine. 2013; 38: E350-E358. doi:10.1097/BRS.0b013e31828435fb

(16) **CAVILL N, KAHLMEIER S, RACIOPPI F.** Physical Activity and Health in Europe: Evidence for Action. 2006, WHO Regional Office for Europe, Copenhagen, Denmark, 55.

(17) **CHOI BK, VERBEEK JH, TAM WW, JIANG JY.** Exercises for prevention of recurrences of low-back pain. Occup Environ Med. 2010; 67: 795-796. doi:10.1136/oem.2010.059873

(18) **CHOU R, QASEEM A, SNOW V, CASEY D, CROSS JT JR, SHEKELLE P, OWENS DK.** Diagnosis and treatment of low back pain: a joint clinical practice guideline from the American College of Physicians and the American Pain Society. Ann Intern Med. 2007; 147: 478-491. doi:10.7326/0003-4819-147-7-200710020-00006

(19) **CLAEYS K, BRUMAGNE S, DANKAERTS W, KIERS H, JANSSENS L.** Decreased variability in postural control strategies in young people with non-specific low back pain is associated with altered proprioceptive reweighting. Eur J Appl Physiol. 2011; 111: 115-123. doi:10.1007/s00421-010-1637-x

(20) **DANNEELS LA, VANDERSTRAETEN GG, CAMBIER DC, WITVROUW EE, DE CUYPER HJ.** CT imaging of trunk muscles in chronic low back pain patients and healthy control subjects. Eur Spine J. 2000; 9: 266-272. doi:10.1007/s005860000190

(21) **FERNANDEZ E.** A classification system of cognitive coping strategies for pain. Pain. 1986; 26: 141-151. doi:10.1016/0304-3959(86)90070-9

(22) **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. Br J Sports Med. 2010; 44: 1166-1172. doi:10.1136/bjsm.2009.061515

(23) **FERSUM KV, DANKAERTS W, O'SULLIVAN PB, MAESJ, SKOUEN JS, BJORDAL JM, KVÅLE A.** Integration of subclassification strategies in randomised controlled clinical trials evaluating manual therapy treatment and exercise therapy for non-specific chronic low back pain: a systematic review. Br J Sports Med. 2010; 44: 1054-1062. doi:10.1136/bjsm.2009.063289

(24) **FRANÇA FR, BURKE TN, HANADA ES, MARQUES AP.** Segmental stabilization and muscular strengthening in chronic low back pain: a comparative study. Clinics (Sao Paulo). 2010; 65: 1013-1017. doi:10.1590/S1807-59322010001000015

(25) **GARG K, WARIKOO D, KARN S.** Efficacy of Sensory Motor Training on Pain, Disability and Function in Patients with Chronic Non-Specific Low Back Pain: An Experimental Study. European Academic Research. 2014; 2: 9111-9121.

(26) **GILL KP, CALLAGHAN MJ.** The measurement of lumbar proprioception in individuals with and without low back pain. Spine. 1998; 23: 371-377. doi:10.1097/00007632-199802010-00017

(27) **GORDON R, BLOXHAM S.** A Systematic Review of the Effects of Exercise and Physical Activity on Non-Specific Chronic Low Back Pain. Healthcare (Basel). 2016; 4.

(28) **HARTIGAN C, RAINVILLE J.** Exercise-based therapy for low back pain. 2018, (ahead of print).

(29) **HASKELL WL, LEE IM, PATE RR, POWELL KE, BLAIR SN, FRANKLIN BA, MACERA CA, HEATH GW, THOMPSON PD, BAUMAN A.** Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. Med Sci Sports Exerc. 2007; 39: 1423-1434. doi:10.1249/mss.0b013e3180616b27

(30) **HAYDEN JA, VAN TULDER MW, MALMIVAARA A, KOES BW.** Exercise therapy for treatment of non-specific low back pain. Cochrane Database Syst Rev. 2005; 3: CD000335.

(31) **HAYDEN JA, VAN TULDER MW, TOMLINSON G.** Systematic review: strategies for using exercise therapy to improve outcomes in chronic low back pain. Ann Intern Med. 2005; 142: 776-785. doi:10.7326/0003-4819-142-9-200505030-00014

(32) **HENCHOZ Y, KAI-LIK SO A.** Exercise and nonspecific low back pain: a literature review. Joint Bone Spine. 2008; 75: 533-539. doi:10.1016/j.jbspin.2008.03.003

(33) **HODGES PW, GANDEVIA SC, RICHARDSON CA.** Contractions of specific abdominal muscles in postural tasks are affected by respiratory maneuvers. J Appl Physiol (1985). 1997; 83: 753-60.

(34) **HODGES PW, RICHARDSON CA.** Inefficient muscular stabilization of the lumbar spine associated with low back pain. A motor control evaluation of transversus abdominis. Spine. 1996; 21: 2640-2650. doi:10.1097/00007632-199611150-00014

(35) **HOTZ-BOENDERMAKER S, MARCAR VL, MEIER ML, BOENDERMAKER B, HUMPHREYS BK.** Reorganization in Secondary Somatosensory Cortex in Chronic Low Back Pain Patients. Spine. 2016; 41: E667-E673. doi:10.1097/BRS.0000000000001348

(36) **HWANG JA, BAE SH, DO KIM G, KIM KY.** The effects of sensorimotor training on anticipatory postural adjustment of the trunk in chronic low back pain patients. J Phys Ther Sci. 2013; 25: 1189-1192. doi:10.1589/jpts.25.1189

(37) **JANDA V.** Muscles, central nervous motor regulation and back problems. In: Korr IM, ed. The Neurobiologic Mechanisms in Manipulative Therapy New York, USA: Plenum Press; 1978: 27-40.

(38) **JONES MD, BOOTH J, TAYLOR JL, BARRY BK.** Aerobic training increases pain tolerance in healthy individuals. Med Sci Sports Exerc. 2014; 46: 1640-1647. doi:10.1249/MSS.0000000000000273

(39) **KAEDING TS, KARCH A, SCHWARZ R, FLOR T, WITTKE T-C, KÜCK M, BÖSELT G, TEGTBUR U, STEIN L.** Whole-body vibration training as a workplace-based sports activity for employees with chronic low-back pain. Scand J Med Sci Sports. 2017; 27: 2027-2039. doi:10.1111/sms.12852

(40) **KEANE LG.** Comparing AquaStretch with supervised land based stretching for Chronic Lower Back Pain. J Bodyw Mov Ther. 2017; 21: 297-305. doi:10.1016/j.jbmt.2016.07.004

(41) **KELLER A, HAYDEN J, BOMBARDIER C, VAN TULDER M.** Effect sizes of non-surgical treatments of non-specific low-back pain. Eur Spine J. 2007; 16: 1776-1788. doi:10.1007/s00586-007-0379-x

(42) **KIM BR, LEE HJ.** Effects of proprioceptive neuromuscular facilitation-based abdominal muscle strengthening training on pulmonary function, pain, and functional disability index in chronic low back pain patients. J Exerc Rehabil. 2017; 13: 486-490. doi:10.12965/jer.1735030.515

(43) **KINSER PA, PAULI J, JALLO N, SHALL M, KARST K, HOEKSTRA M, STARKWEATHER A.** Physical Activity and Yoga-Based Approaches for Pregnancy-Related Low Back and Pelvic Pain. J Obstet Gynecol Neonatal Nurs. 2017; 46: 334-346. doi:10.1016/j.jogn.2016.12.006

(44) **KOFOTOLIS N, KELLIS E, VLACHOPOULOS SP, GOUITAS I, THEODORAKIS Y.** Effects of Pilates and trunk strengthening exercises on health-related quality of life in women with chronic low back pain. J Back Musculoskeletal Rehabil. 2016; 29: 649-659. doi:10.3233/BMR-160665

(45) **LA TOUCHE R, ESCALANTE K, LINARES MT.** Treating non-specific chronic low back pain through the Pilates Method. J Bodyw Mov Ther. 2008; 12: 364-370. doi:10.1016/j.jbmt.2007.11.004

(46) **LEINONEN V, KANKAANPAA M, LUUKKONEN M, HANNINEN O, AIRAKSINEN O, TAIMELA S.** Disc herniation-related back pain impairs feed-forward control of paraspinal muscles. Spine. 2001; 26: E367-E372. doi:10.1097/00007632-200108150-00014

(47) **LETAFATKAR A, NAZARZADEH M, HADADNEZHAD M, FARIVAR N.** The efficacy of a HUBER exercise system mediated sensorimotor training protocol on proprioceptive system, lumbar movement control and quality of life in patients with chronic non-specific low back pain. J Back Musculoskeletal Rehabil. 2017; 30: 767-778. doi:10.3233/BMR-150404

(48) **LIDDLE SD, BAXTER GD, GRACEY JH.** Exercise and chronic low back pain: what works? Pain. 2004; 107: 176-190. doi:10.1016/j.pain.2003.10.017

(49) **LIZIER DT, PEREZ MV, SAKATA RK.** Exercises for treatment of nonspecific low back pain. Rev Bras Anestesiol. 2012; 62: 838-846. doi:10.1016/S0034-7094(12)70183-6

(50) **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. doi:10.2522/ptj.20080103

(51) **MACEDO LG, BOSTICK GP, MAHER CG.** Exercise for prevention of recurrences of nonspecific low back pain. Phys Ther. 2013; 93: 1587-1591. doi:10.2522/ptj.20120464

(52) **MAYER F.** Medicine in Spine Network. 2017; MiSpEx Homepage. http://mispex.de/ [15th September 2017].

(53) **MAYER F, MUELLER S.** Rückenschmerzen - was wirkt? Sportärztezeitung. 2016; 3: 2-4.

(54) **MCCASKEY MA, SCHUSTER-AMFT C, WIRTH B, DE BRUIN ED.** Effects of postural specific sensorimotor training in patients with chronic low back pain: study protocol for randomised controlled trial. Trials. 2015; 16: 571. doi:10.1186/s13063-015-1104-4

(55) **MCGILL SM, GRENIER S, KAVCIC N, CHOLEWICKI J.** Coordination of muscle activity to assure stability of the lumbar spine. J Electromyogr Kinesiol. 2003; 13: 353-359. doi:10.1016/S1050-6411(03)00043-9

(56) **NEWCOMER KL, LASKOWSKI ER, YU B, JOHNSON JC, AN KN.** Differences in repositioning error among patients with low back pain compared with control subjects. Spine. 2000; 25: 2488-2493. doi:10.1097/00007632-200010010-00011

(57) **NIEDERER D, VOGT L, WIPPERT PM, PUSCHMANN A-K, PFEIFER A-C, SCHILTENWOLF M, BANZER A, MAYER F.** Medicine in spine exercise (MiSpEx) for nonspecific low back pain patients: study protocol for a multicentre, single-blind randomized controlled trial. Trials. 2016; 17: 507. doi:10.1186/s13063-016-1645-1

(58) **O'SULLIVAN PB, PHYTY GD, TWOMEY LT, ALLISON GT.** Evaluation of specific stabilizing exercise in the treatment of chronic low back pain with radiologic diagnosis of spondylolysis or spondylolisthesis. Spine. 1997; 22: 2959-2967. doi:10.1097/00007632-199712150-00020

(59) **PAGE P.** Sensorimotor training: A "global" approach for balance training. J Bodyw Mov Ther. 2006; 10: 77-84. doi:10.1016/j.jbmt.2005.04.006

(60) **PAGE P, FRANK CC, LARDNER R.** Assessment and Treatment of muscle imbalance: The Janda Approach. Champaing, IL, USA: Human Kinetics; 2010.

(61) **PANJABI MM.** The stabilizing system of the spine. Part I. Function, dysfunction, adaptation, and enhancement. J Spinal Disord. 1992; 5: 383-389, discussion 397. doi:10.1097/00002517-199212000-00001

(62) **PIJNENBURG M, CAEYENBERGHS K, JANSSENS L, GOOSSENS N, SWINNEN SP, SUNAERT S, BRUMAGNE S.** Microstructural integrity of the superior cerebellar peduncle is associated with an impaired proprioceptive weighting capacity in individuals with non-specific low back pain. PLoS ONE. 2014; 9: e100666. doi:10.1371/journal.pone.0100666

(63) **RADEBOLD A, CHOLEWICKI J, POLZHOFER GK, GREENE HS.** Impaired postural control of the lumbar spine is associated with delayed muscle response times in patients with chronic idiopathic low back pain. Spine. 2001; 26: 724-730. doi:10.1097/00007632-200104010-00004

(64) **RAINVILLE J, HARTIGAN C, MARTINEZ E, LIMKE J, JOUVE C, FINNO M.** Exercise as a treatment for chronic low back pain. Spine J. 2004; 4: 106-115. doi:10.1016/S1529-9430(03)00174-8

(65) **RAMOS LAV, FRANCA FJR, CALLEGARI B, BURKE TN, MAGALHAES MO, MARQUES AP.** Are lumbar multifidus fatigue and transversus abdominis activation similar in patients with lumbar disc herniation and healthy controls? A case control study. Eur Spine J. 2016; 25: 1435-1442. doi:10.1007/s00586-015-4375-2

(66) **REEVES NP, NARENDRA KS, CHOLEWICKI J.** Spine stability: the six blind men and the elephant. Clin Biomech (Bristol, Avon). 2007; 22: 266-274. doi:10.1016/j.clinbiomech.2006.11.011

(67) **SARAGIOTTO BT, MAHER CG, YAMATO TP, SARAGIOTTO BT, MAHER CG, YAMATO TP, COSTA LO, MENEZES COSTA LC, OSTELO RW, MACEDO LG.** Motor control exercise for chronic non-specific low-back pain. Cochrane Database Syst Rev. 2016; 1: CD012004. doi:10.1002/14651858.CD012004

(68) **SEARLE A, SPINK M, HO A, CHUTER V.** Exercise interventions for the treatment of chronic low back pain: a systematic review and meta-analysis of randomised controlled trials. Clin Rehabil. 2015; 29: 1155-1167. doi:10.1177/0269215515570379

(69) **SERAFINO EP.** Health psychology. Vol 6th edition. Hoboken, NY, USA: John Wiley & Sons; 2008.

(70) **SODERBERG GL, BARR JO.** Muscular function in chronic low-back dysfunction. Spine. 1983; 8: 79-85. doi:10.1097/00007632-198301000-00014

(71) **STUBBS B, BINNEKADE TT, SOUNDY A, SCHOFIELD P, HUIJNEN IP, EGGERMONT LH.** Are older adults with chronic musculoskeletal pain less active than older adults without pain? A systematic review and meta-analysis. Pain Med. 2013; 14: 1316-1331. doi:10.1111/pme.12154

(72) **TSAO H, GALEA MP, HODGES PW.** Reorganization of the motor cortex is associated with postural control deficits in recurrent low back pain. Brain. 2008; 131: 2161-2171. doi:10.1093/brain/awn154

(73) **VAN MIDDELKOOP M, RUBINSTEIN SM, KUIJPERS T, VERHAGEN AP, OSTELO R, KOES BW, VAN TULDER MW.** A systematic review on the effectiveness of physical and rehabilitation interventions for chronic non-specific low back pain. Eur Spine J. 2011; 20: 19-39. doi:10.1007/s00586-010-1518-3

(74) **VAN MIDDELKOOP M, RUBINSTEIN SM, VERHAGEN AP, OSTELO RW, KOES BW, VAN TULDER MW.** Exercise therapy for chronic nonspecific low-back pain. Best Pract Res Clin Rheumatol. 2010; 24: 193-204. doi:10.1016/j.berh.2010.01.002

(75) **VAN TULDER M, MALMIVAARA A, ESMAIL R, KOES B.** Exercise therapy for low back pain: a systematic review within the framework of the cochrane collaboration back review group. Spine. 2000; 25: 2784-2796. doi:10.1097/00007632-200011010-00011

(76) **VERBUNT JA, SMEETS RJ, WITTINK HM.** Cause or effect? Deconditioning and chronic low back pain. Pain. 2010; 149: 428-430. doi:10.1016/j.pain.2010.01.020

(77) **WANG XQ, ZHENG JJ, YU ZW, BI X, LOU SJ, LIU J, CAI B, HUA YH, WU M, WEI ML, SHEN HM, CHEN Y, PAN YJ, XU GH, CHEN PJ.** A meta-analysis of core stability exercise versus general exercise for chronic low back pain. PLoS ONE. 2012; 7: e52082. doi:10.1371/journal.pone.0052082

(78) **WHO.** Global Recommendations on Physical Activity for Health Geneva; 2010.

(79) **WIELAND LS, SKOETZ N, PILKINGTON K, VEMPATI R, D'ADAMO CR, BERMAN BM.** Yoga treatment for chronic non-specific low back pain. Cochrane Database Syst Rev. 2017; 1: CD010671.

(80) **YOUNG KJ, JE CW, HWA ST.** Effect of proprioceptive neuromuscular facilitation integration pattern and swiss ball training on pain and balance in elderly patients with chronic back pain. J Phys Ther Sci. 2015; 27: 3237-3240. doi:10.1589/jpts.27.3237

(81) **YUE YS, WANG XD, XIE B, LI ZH, CHEN BL, WAN XQ, ZHU Y.** Sling exercise for chronic low back pain: a systematic review and meta-analysis. PLoS ONE. 2014; 9: e99307. doi:10.1371/journal.pone.0099307