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Effects of Core-Stability Training on Performance and Injuries in Competitive Athletes

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| Most competitive athletes perform core-stability training to some extent. In the slideshow accompanying this article we provide a critical overview of scientific studies exploring the relationship between core stability and athletic performance, injury prevention and injury rehabilitation. We also identify methodological limitations and concerns associated with these investigations and provide recommendations for training and rehabilitation. The field suffers from the lack of terminological consensus, and the varying definitions of *core* can make for confusion as they involve diverse anatomy (e.g., with or without limbs). It is also problematic that parts of the theoretical framework related to core stability have emerged from studies of low back pain, questioning the relevance to athletes. Numerous tests have been proposed to assess core stability, but no universal standards have so far been developed. The proposed core stability tests either have poor validity and reliability or have not been assessed for validity and reliability at all. Targeted core-stability training interventions have in some cases provided positive effects on sport-specific tasks (e.g., throwing velocity). A few cross-sectional studies have reported small-to-moderate relationships among core stability and some sport-specific tasks with strong core components (e.g., baseball pitching/batting, golf, tennis serve). However, a causal relationship between core stability and athletic performance has not been established, owing to limitations in previous study designs. Moreover, poor core stability in isolation is not a predominant risk factor for athletic injuries. Stabilization training of the core may enhance the recovery time for certain injuries, but no better than any other training forms in the long term. In conclusion, isolated core stability training should not be the primary emphasis for programs with the goal of enhancing athletic performance, preventing injuries or reducing injury recovery time. More research in the field is needed for operational definition purposes, developing valid and reliable core stability tests, and exploring cause-effect relationships among core stability and athletic performance, injury prevention and rehabilitation. KEYWORDS: lumbo-pelvic stability, rehabilitation, stabilization.[Reprint pdf](TH.pdf) · [Reprint docx](TH.docx) · [Slideshow](Core_training_Haugen_et_al_Sportscience_2016.pptx) (6.3 MB)[References](Core-training_references.txt) (in RefMan/RIS format) |

More than a decade ago, several authors proposed that core stability was essential for athletic performance and injury prevention ([Hodges and Richardson, 1996](#_ENREF_7); [Hodges and Richardson, 1998](#_ENREF_8); [Kibler et al., 2006](#_ENREF_10)). Their theories were based mainly on studies dealing with low back pain patients. The arguments and recommendations from these studies were promptly accepted and adopted by the fitness industry ([Willardson, 2007](#_ENREF_20)). The early studies have been cited frequently, as they provide a point of departure for further investigations within the topic, and the importance of core stability on athletic performance and injury prevention has been heavily debated the last decade. Definitions of the term *core stability* vary across studies according to the context in which they are viewed. However, most authors generally incorporate the trunk into the core definition, with special emphasis on the lumbo-pelvic region of the body ([Willardson, 2007](#_ENREF_20)). The stabilizing system consists of passive (ligaments and bones), active (muscles) and neural structures ([Panjabi, 1992](#_ENREF_13)).

Do competitive, high-level athletes perform core training? If we look to scientific publications, the general training patterns of world-class performers in a broad range of sport disciplines have been described, including ice hockey ([Ebben et al., 2004](#_ENREF_4)), rowing ([Fiskerstrand and Seiler, 2004](#_ENREF_5)), cross-country skiing ([Sandbakk and Holmberg, 2014](#_ENREF_16); [Tonnessen et al., 2014](#_ENREF_17)), biathlon ([Tonnessen et al., 2014](#_ENREF_17)), speed skating ([Orie et al., 2014](#_ENREF_12)), soccer ([Malone et al., 2015](#_ENREF_11)), orienteering ([Tonnessen et al., 2015b](#_ENREF_19)) and Nordic Combined ([Tonnessen et al., 2015a](#_ENREF_18)). Unfortunately, these studies do not reveal to what extent core training has been performed, as core training was not quantified.

As conditioning experts and physiotherapists at the Norwegian Olympic Training Centre, the present authors have in-depth knowledge of daily training and rehabilitation programs for a large number of high-level performers. Our inspection of training sessions, training diaries and conversations with athletes and coaches) reveals that core training is performed by world-class athletes in cross-country skiing, biathlon, ski jumping, Nordic combined, speed skating, snowboard, alpine skiing, ice hockey, soccer, handball, rowing, kayak, swimming, cycling, golf, sailing, taekwondo, wrestling, orienteering and athletics. Indeed, core training is one of very few training forms common for all these sport disciplines. The total weekly core training volume varies considerably among individuals and sport disciplines, ranging from 5 min to 2 h per week. Anecdotally, cross-country skiers, rowers, kayakers, sailors and golfers typically perform more core training than other athlete groups. However, a common trend among most individuals is higher core training volume during preparation periods compared to competition periods. Moreover, core training is performed more during injury rehabilitation periods, when sport-specific training is prohibited.

High prevalence of low back pain during a season has been reported in athlete populations such as cross-country skiing ([Alricsson and Werner, 2005](#_ENREF_1); [Alricsson and Werner, 2006](#_ENREF_2); [Bahr et al., 2004](#_ENREF_3); [Foss et al., 2012](#_ENREF_6)), rowing ([Bahr et al., 2004](#_ENREF_3); [Foss et al., 2012](#_ENREF_6)), orienteering ([Bahr et al., 2004](#_ENREF_3); [Foss et al., 2012](#_ENREF_6)), gymnastics and rhythmic gymnastics ([Purcell and Micheli, 2009](#_ENREF_15)). Competitive young cross-country skiers relieved back pain by changing body position during exercise ([Alricsson and Werner, 2005](#_ENREF_1)), emphasizing the importance of preventive strategies such as core training to reduce back pain. Core stability training is often used in athletic populations for back-pain treatment ([Puentedura and Louw, 2012](#_ENREF_14)). Pain affects motor control ([Hodges and Moseley, 2003](#_ENREF_9)), and some therefore argue that clinicians’ management of athletes with low-back pain should include training and biopsychosocial approaches ([Puentedura and Louw, 2012](#_ENREF_14)).

Although core training is not the main training form for any sport discipline, the majority of competitive athletes perform such training to some extent. In addition, even though the core is a popular target for athletic conditioning in general, questions remain regarding training effects, overall performance benefits, injury prevention and rehabilitation from injury. Therefore, we had three objectives in preparing a tutorial presentation on core training: to provide a critical overview of scientific studies exploring the relationship between core stability and athletic performance, injury prevention, and injury rehabilitation; to identify methodological limitations and concerns associated with these investigations; and to provide specific recommendations for core training and rehabilitation.

# References(See below for references cited in the slideshow.)

Alricsson M, Werner S (2005). Self-reported health, physical activity and prevalence of complaints in elite cross-country skiers and matched controls. Journal of Sports Medicine and Physical Fitness 45, 547-552

Alricsson M, Werner S (2006). Young elite cross-country skiers and low back pain-A 5-year study. Physical Therapy in Sport 7, 181-184

Bahr R, Andersen SO, Løken S, Fossan B, Hansen T, Holme I (2004). Low back pain among endurance athletes with and without specific back loading-a cross-sectional survey of cross-country skiers, rowers, orienteerers, and nonathletic controls. Spine 29, 449-454

Ebben WP, Carroll RM, Simenz CJ (2004). Strength and conditioning practices of National Hockey League strength and conditioning coaches. Journal of Strength and Conditioning Research 18, 889-897

Fiskerstrand A, Seiler KS (2004). Training and performance characteristics among Norwegian international rowers 1970-2001. Scandinavian Journal of Medicine and Science in Sports 14, 303-310

Foss IS, Holme I, Bahr R (2012). The prevalence of low back pain among former elite cross-country skiers, rowers, orienteerers, and nonathletes: a 10-year cohort study. American Journal of Sports Medicine 40, 2610-2616

Hodges PW, Richardson CA (1996). Inefficient muscular stabilization of the lumbar spine associated with low back pain. A motor control evaluation of transversus abdominis. Spine 21, 2640-2650

Hodges PW, Richardson CA (1998). Delayed postural contraction of transversus abdominis in low back pain associated with movement of the lower limb. Journal of Spinal Disorders 11, 46-56

Hodges PW, Moseley GL (2003). Pain and motor control of the lumbopelvic region: effect and possible mechanisms. Journal of Electromyography and Kinesiology 13, 361-370

Kibler WB, Press J, Sciascia A (2006). The role of core stability in athletic function. Sports Medicine 36, 189-198

Malone JJ, Di Michele R, Morgans R, Burgess D, Morton JP, Drust B (2015). Seasonal training-load quantification in elite English premier league soccer players. International Journal of Sports Physiology and Performance 10, 489-497

Orie J, Hofman N, de Koning JJ, Foster C (2014). Thirty-eight years of training distribution in Olympic speed skaters. International Journal of Sports Physiology and Performance 9, 93-99

Panjabi MM (1992). The stabilizing system of the spine. Part II. Neutral zone and instability hypothesis. Journal of Spinal Disorders 5, 390-396

Puentedura EJ, Louw A (2012). A neuroscience approach to managing athletes with low back pain. Physical Therapy in Sport 13, 123-133

Purcell L, Micheli L (2009). Low back pain in young athletes. Sports Health 1, 212-222

Sandbakk O, Holmberg HC (2014). A reappraisal of success factors for Olympic cross-country skiing. International Journal of Sports Physiology and Performance 9, 117-121

Tonnessen E, Sylta O, Haugen TA, Hem E, Svendsen IS, Seiler S (2014). The road to gold: training and peaking characteristics in the year prior to a gold medal endurance performance. PLoS One 9, e101796

Tonnessen E, Rasdal V, Svendsen IS, Haugen TA, Hem E, Sandbakk O (2015a). Concurrent development of endurance capacity and explosiveness: The training characteristics of world-class nordic combined athletes. International Journal of Sports Physiology and Performance, 10.1123/ijspp.2015-0309

Tonnessen E, Svendsen IS, Ronnestad BR, Hisdal J, Haugen TA, Seiler S (2015b). The annual training periodization of 8 world champions in orienteering. International Journal of Sports Physiology and Performance 10, 29-38

Willardson JM (2007). Core stability training: applications to sports conditioning programs. Journal of Strength and Conditioning Research 21, 979-985

# References Cited in Slideshow

Baechle TR, Earle RW, Wathen D (2000). Resistance training. In: Baechle TR, Earle RW (editors) Essentials of strength training and conditioning. Human Kinetics. 395-425

Bahr R, Lian O, Bahr IA (1997). A twofold reduction in the incidence of acute ankle sprains in volleyball after the introduction of an injury prevention program: a prospective cohort study. Scandinavian Journal of Medicine and Science in Sports 7, 172-177

Baker D (1996). Improving vertical jump performance through general, special, and specific strength training: A brief review. Journal of Strength and Conditioning Research 10, 131-136

Bardenett SM, Micca JJ, DeNoyelles JT, Miller SD, Jenk DT, Brooks GS (2015). Functional movement screen normative values and validity in high school athletes: Can the FMS be used as a predictor of injury? International Journal of Sports Physical Therapy 10, 303-308

Barnett F, Gilleard W (2005). The use of lumbar spinal stabilization techniques during the performance of abdominal strengthening exercise variations. . Journal of Sports Medicine and Physical Fitness 45, 38-43

Barton CJ, Lack S, Malliaras P, Morrissey D (2013). Gluteal muscle activity and patellofemoral pain syndrome: a systematic review. British Journal of Sports Medicine 47, 207-214

Barton CJ, Lack S, Hemmings S, Tufail S, Morrissey D (2015). The 'best practice guide to conservative management of patellofemoral pain': incorporating level 1 evidence with expert clinical reasoning. British Journal of Sports Medicine 49, 923-934

Behm DG, Drinkwater EJ, Willardson JM, Cowley PM (2010). The use of instability to train the core musculature. Applied Physiology Nutrition and Metabolism 35, 91-108

Bergmark A (1989). Stability of the lumbar spine. A study in mechanical engineering. Acta Orthopaedica Scandinavica. Supplementum 230, 1-54

Bien DP (2011). Rationale and implementation of anterior cruciate ligament injury prevention warm-up programs in female athletes. Journal of Strength and Conditioning Research 25, 271-285

Borghuis J, Hof AL, Lemmink KA (2008). The importance of sensory-motor control in providing core stability: implications for measurement and training. Sports Medicine 38, 893-916

Boscolo Del Vecchio F, Foster D, Arruda A (2016). Functional Movement Screening performance of Brazilian jiu-jitsu athletes from Brazil: differences considering practice time and combat style. Journal of Strength and Conditioning Research (in press)

Bushman TT, Grier TL, Canham-Chervak MC, Anderson MK, North WJ, Jones BH (2015). Pain on functional movement screen tests and injury risk. Journal of Strength and Conditioning Research 29, 65-70

Bushman TT, Grier TL, Canham-Chervak M, Anderson MK, North WJ, Jones BH (2016). The functional movement screen and injury risk: Association and predictive value in active men. American Journal of Sports Medicine 44, 297-304

Butler RJ, Contreras M, Burton LC, Plisky PJ, Goode A, Kiesel K (2013). Modifiable risk factors predict injuries in firefighters during training academies. Work 46, 11-17

Caraffa A, Cerulli G, Projetti M, Aisa G, Rizzo A (1996). Prevention of anterior cruciate ligament injuries in soccer. A prospective controlled study of proprioceptive training. Knee Surgery, Sports Traumatology, Arthroscopy 4, 19-21

Carpes FP, Reinehr FB, Mota CB (2008). Effects of a program for trunk strength and stability on pain, low back and pelvis kinematics, and body balance: a pilot study. Journal of Bodywork and Movement Therapies 12, 22-30

Chapman DW, Needham KJ, Allison GT, Lay B, Edwards DJ (2008). Effects of experience in a dynamic environment on postural control. British Journal of Sports Medicine 42, 16-21

Chapman RF, Laymon AS, Arnold T (2014). Functional movement scores and longitudinal performance outcomes in elite track and field athletes. International Journal of Sports Physiology and Performance 9, 203-211

Chaudhari AM, McKenzie CS, Pan X, Onate JA (2014). Lumbopelvic control and days missed because of injury in professional baseball pitchers. American Journal of Sports Medicine 42, 2734-2740

Cholewicki J, Juluru K, McGill SM (1999). Intra-abdominal pressure mechanism for stabilizing the lumbar spine. Journal of Biomechanics 32, 13-17

Cholewicki J, Polzhofer GK, Radebold A (2000). Postural control of trunk during unstable sitting. Journal of Biomechanics 33, 1733-1737

Cholewicki J, Silfies SP, Shah RA, Greene HS, Reeves NP, Alvi K, Goldberg B (2005). Delayed trunk muscle reflex responses increase the risk of low back injuries. Spine 30, 2614-2620

Chorba RS, Chorba DJ, Bouillon LE, Overmyer CA, Landis JA (2010). Use of a functional movement screening tool to determine injury risk in female collegiate athletes. North American Journal of Sports Physical Therapy 5, 47-54

Cook G, Burton L, Hoogenboom B (2006a). Pre-participation screening: the use of fundamental movements as an assessment of function - part 2. North American Journal of Sports Physical Therapy 1, 132-139

Cook G, Burton L, Hoogenboom B (2006b). Pre-participation screening: the use of fundamental movements as an assessment of function - part 1. North American Journal of Sports Physical Therapy 1, 62-72

Cresswell AG, Oddsson L, Thorstensson A (1994). The influence of sudden perturbations on trunk muscle activity and intra-abdominal pressure while standing. Experimental Brain Research 98, 336-341

Ebenbichler GR, Oddsson LI, Kollmitzer J, Erim Z (2001). Sensory-motor control of the lower back: implications for rehabilitation. Medicine and Science in Sports and Exercise 33, 1889-1898

Ekstrom RA, Donatelli RA, Carp KC (2007). Electromyographic analysis of core trunk, hip, and thigh muscles during 9 rehabilitation exercises. Journal of Orthopaedic and Sports Physical Therapy 37, 754-762

Endo Y, Sakamoto M (2014). Correlation of shoulder and elbow injuries with muscle tightness, core stability, and balance by longitudinal measurements in junior high school baseball players. Journal of Physical Therapy Science 26, 689-693

Engebretsen AH, Myklebust G, Holme I, Engebretsen L, Bahr R (2008). Prevention of injuries among male soccer players: a prospective, randomized intervention study targeting players with previous injuries or reduced function. American Journal of Sports Medicine 36, 1052-1060

Faries MD, Greenwood M (2007). Core training: stabilising the confusion. Strength and Conditioning Journal 29, 10-25

Fernandez-Fernandez J, Ellenbecker T, Sanz-Rivas D, Ulbricht A, Ferrautia A (2013). Effects of a 6-week junior tennis conditioning program on service velocity. Journal of Sports Science and Medicine 12, 232-239

Fig G (2005). Sport-specific conditioning: strength training for swimmers - training the core. Strength and Conditioning Journal 27, 40-42

Garrison M, Westrick R, Johnson MR, Benenson J (2015). Association between the functional movement screen and injury development in college athletes. International Journal of Sports Physical Therapy 10, 21-28

Gottschall JS, Mills J, Hastings B (2013). Integration core exercises elicit greater muscle activation than isolation exercises. Journal of Strength and Conditioning Research 27, 590-596

Grygorowicz M, Piontek T, Dudzinski W (2013). Evaluation of functional limitations in female soccer players and their relationship with sports level--a cross sectional study. PLoS One 8, e66871

Hammes D, Aus der Funten K, Bizzini M, Meyer T (2016). Injury prediction in veteran football players using the Functional Movement Screen. Journal of Sports Sciences 3, 1-9

Harrington S, Meisel C, Tate A (2014). A cross-sectional study examining shoulder pain and disability in Division I female swimmers. Journal of Sport Rehabilitation 23, 65-75

Hewett TE, Paterno MV, Myer GD (2002). Strategies for enhancing proprioception and neuromuscular control of the knee. Clinical Orthopaedics and Related Research 402, 76-94

Hewett TE, Torg JS, Boden BP (2009). Video analysis of trunk and knee motion during non-contact anterior cruciate ligament injury in female athletes: lateral trunk and knee abduction motion are combined components of the injury mechanism. British Journal of Sports Medicine 43, 417-422

Hibbs AE, Thompson KG, French D, Wrigley A, Spears I (2008). Optimizing performance by improving core stability and core strength. Sports Medicine 38, 995-1008

Hides JA, Stanton WR, Mendis MD, Gildea J, Sexton MJ (2012). Effect of motor control training on muscle size and football games missed from injury. Medicine and Science in Sports and Exercise 44, 1141-1149

Hides JA, Stanton WR (2014). Can motor control training lower the risk of injury for professional football players? Medicine and Science in Sports and Exercise 46, 762-768

Hill J, Leiszler M (2011). Review and role of plyometrics and core rehabilitation in competitive sport. Current Sports Medicine Reports 10, 345-351

Hirashima M, Kadota H, Sakurai S, Kudo K, Ohtsuki T (2002). Sequential muscle activity and its functional role in the upper extremity and trunk during overarm throwing. Journal of Sports Sciences 20, 301-310

Hirashima M, Kudo K, Ohtsuki T (2003). Utilization and compensation of interaction torques during ball-throwing movements. Journal of Neurophysiology 89, 1784-1796

Hodges PW, Richardson CA (1996). Inefficient muscular stabilization of the lumbar spine associated with low back pain. A motor control evaluation of transversus abdominis. Spine 21, 2640-2650

Hodges PW, Richardson CA (1997a). Feedforward contraction of transversus abdominis is not influenced by the direction of arm movement. Experimental Brain Research 114, 362-370

Hodges PW, Richardson CA (1997b). Contraction of the abdominal muscles associated with movement of the lower limb. Physical Therapy 77, 132-142

Hodges PW (2003). Core stability exercise in chronic low back pain. Orthopedic Clinics of North America 34, 245-254

Holmich P, Larsen K, Krogsgaard K, Gluud C (2010). Exercise program for prevention of groin pain in football players: a cluster-randomized trial. Scandinavian Journal of Medicine and Science in Sports 20, 814-821

Hopkins WG (2004). How to interpret changes in an athletic performance test. Sportscience 8, 1-7

Hotta T, Nishiguchi S, Fukutani N, Tashiro Y, Adachi D, Morino S, Shirooka H, Nozaki Y, Hirata H, Yamaguchi M, Aoyama T (2015). Functional movement screen for predicting running injuries in 18- to 24-year-old competitive male runners. Journal of Strength and Conditioning Research 29, 2808-2815

Hrysomallis C (2007). Relationship between balance ability, training and sports injury risk. Sports Medicine 37, 547-556

Hrysomallis C, McLaughlin P, Goodman C (2007). Balance and injury in elite Australian footballers. International Journal of Sports Medicine 28, 844-847

Huxel Bliven KC, Anderson BE (2013). Core stability training for injury prevention. Sports Health 5, 514-522

Kiani A, Hellquist E, Ahlqvist K, Gedeborg R, Michaelsson K, Byberg L (2010). Prevention of soccer-related knee injuries in teenaged girls. Archives of Internal Medicine 170, 43-49

Kibler WB (1995). Biomechanical analysis of the shoulder during tennis activities. Clinics in Sports Medicine 14, 79-85

Kibler WB, Press J, Sciascia A (2006). The role of core stability in athletic function. Sports Medicine 36, 189-198

Kiesel K, Plisky PJ, Voight ML (2007). Can serious injury in professional football be predicted by a preseason functional movement screen? North American Journal of Sports Physical Therapy 2, 147-158

Kiesel KB, Butler RJ, Plisky PJ (2014). Prediction of injury by limited and asymmetrical fundamental movement patterns in american football players. Journal of Sports Rehabilitation 23, 88-94

Knapik JJ, Bullock SH, Canada S, Toney E, Wells JD, Hoedebecke E, Jones BH (2004). Influence of an injury reduction program on injury and fitness outcomes among soldiers. Injury Prevention 10, 37-42

Knapik JJ, Cosio-Lima LM, Reynolds KL, Shumway RS (2015). Efficacy of functional movement screening for predicting injuries in coast guard cadets. Journal of Strength and Conditioning Research 29, 1157-1162

Lauersen JB, Bertelsen DM, Andersen LB (2014). The effectiveness of exercise interventions to prevent sports injuries: a systematic review and meta-analysis of randomised controlled trials. British Journal of Sports Medicine 48, 871-877

Lederman E (2010). The myth of core stability. Journal of Bodywork and Movement Therapies 14, 84-98

Leetun DT, Ireland ML, Willson JD, Ballantyne BT, Davis IM (2004). Core stability measures as risk factors for lower extremity injury in athletes. Medicine and Science in Sports and Exercise 36, 926-934

Lehman GJ (2006). Resistance training for performance and injury prevention in golf. Journal of the Canadian Chiropractic Association 50, 27-42

Liemohn WP, Baumgartner TA, Gagnon LH (2005). Measuring core stability. Journal of Strength and Conditioning Research 19, 583-586

Lloyd RS, Oliver JL, Radnor JM, Rhodes BC, Faigenbaum AD, Myer GD (2015). Relationships between functional movement screen scores, maturation and physical performance in young soccer players. Journal of Sports Sciences 33, 11-19

Lockie R, Schultz A, Callaghan S, Jordan C, Luczo T, Jeffriess M (2015a). A preliminary investigation into the relationship between functional movement screen scores and athletic physical performance in female team sport athletes. Biology of Sport 32, 41-51

Lockie RG, Schultz AB, Jordan CA, Callaghan SJ, Jeffriess MD, Luczo TM (2015b). Can selected functional movement screen assessments be used to identify movement deficiencies that could affect multidirectional speed and jump performance? Journal of Strength and Conditioning Research 29, 195-205

Loudon JK, Parkerson-Mitchell AJ, Hildebrand LD, Teague C (2014). Functional movement screen scores in a group of running athletes. Journal of Strength and Conditioning Research 28, 909-913

Marshall RN, Elliott BC (2000). Long-axis rotation: the missing link in proximal-to-distal segmental sequencing. Journal of Sports Sciences 18, 247-254

McGill S (2002). Low back disorders: evidence-based prevention and rehabilitation. Human Kinetics: Champaign, Il, p. 1-295

McGill SM (1998). Low back exercises: evidence for improving exercise regimens. Physical Therapy 78, 754-765

McGill SM, Childs A, Liebenson C (1999). Endurance times for low back stabilization exercises: clinical targets for testing and training from a normal database. Archives of Physical Medicine and Rehabilitation 80, 941-944

McGill SM, Cholewicki J (2001). Biomechanical basis for stability: an explanation to enhance clinical utility. Journal of Orthopaedic and Sports Physical Therapy 31, 96-100

McGill SM, Karpowicz A (2009). Exercises for spine stabilization: motion/motor patterns, stability progressions, and clinical technique. Archives of Physical Medicine and Rehabilitation 90, 118-126

McGuine TA, Greene JJ, Best T, Leverson G (2000). Balance as a predictor of ankle injuries in high school basketball players. Clinical Journal of Sport Medicine 10, 239-244

Mendiguchia J, Ford KR, Quatman CE, Alentorn-Geli E, Hewett TE (2011). Sex differences in proximal control of the knee joint. Sports Medicine 41, 541-557

Mokha M, Sprague PA, Gatens DR (2016). Predicting musculoskeletal injury in National Collegiate Athletic Association Division II athletes from asymmetries and individual-test versus composite functional movement screen scores. Journal of Athletic Training, doi 10.4085/1062-6050-4051.4082.4007

Mononen K, Konttinen N, Viitasalo J, Era P (2007). Relationships between postural balance, rifle stability and shooting accuracy among novice rifle shooters. Scandinavian Journal of Medicine and Science in Sports 17, 180-185

Myer GD, Ford KR, Palumbo JP, Hewett TE (2005). Neuromuscular training improves performance and lower-extremity biomechanics in female athletes. . Journal of Strength and Conditioning Research 19, 51-60

Myklebust G, Engebretsen L, Braekken IH, Skjolberg A, Olsen OE, Bahr R (2003). Prevention of anterior cruciate ligament injuries in female team handball players: a prospective intervention study over three seasons. Clinical Journal of Sport Medicine 13, 71-78

Nadler SF, Malanga GA, Feinberg JH, Prybicien M, Stitik TP, DePrince M (2001). Relationship between hip muscle imbalance and occurrence of low back pain in collegiate athletes: a prospective study. American Journal of Physical Medicine and Rehabilitation 80, 572-577

Nadler SF, Malanga GA, Bartoli LA, Feinberg JH, Prybicien M, Deprince M (2002). Hip muscle imbalance and low back pain in athletes: influence of core strengthening. Medicine and Science in Sports and Exercise 34, 9-16

Nagar VR, Hooper TL, Dedrick GS, Brismee JM, Sizer PS, Jr. (2014). Effect of recurrent low back pain history on volitional pre-emptive abdominal activation during a loaded functional reach activity. Spine 39, 89-96

Noe F, Paillard T (2005). Is postural control affected by expertise in alpine skiing? British Journal of Sports Medicine 39, 835-837

O'Connor FG, Deuster PA, Davis J, Pappas CG, Knapik JJ (2011). Functional movement screening: predicting injuries in officer candidates. Medicine and Science in Sports and Exercise 43, 2224-2230

O ́Sullivan PL, Ivan M (2014). Acute low back pain beyond drug therapies. Pain Management Today 1, 8-13

O’Sullivan PB (2000). Lumbar segmental `instability': clinical presentation and specific stabilizing exercise management. Manual Therapy 5, 2-12

Okada T, Huxel KC, Nesser TW (2011). Relationship between core stability, functional movement, and performance. Journal of Strength and Conditioning Research 25, 252-261

Olsen OE, Myklebust G, Engebretsen L, Holme I, Bahr R (2005). Exercises to prevent lower limb injuries in youth sports: cluster randomised controlled trial. BMJ 330, 1-7

Paillard T, Costes-Salon C, Lafont C, Dupui P (2002). Are there differences in postural regulation according to the level of competition in judoists? British Journal of Sports Medicine 36, 304-305

Paillard T, Noe F (2006). Effect of expertise and visual contribution on postural control in soccer. Scandinavian Journal of Medicine and Science in Sports 16, 345-348

Paillard T, Noe F, Riviere T, Marion V, Montoya R, Dupui P (2006). Postural performance and strategy in the unipedal stance of soccer players at different levels of competition. Journal of Athletic Training 41, 172-176

Panjabi MM (1992). The stabilizing system of the spine. Part II. Neutral zone and instability hypothesis. Journal of Spinal Disorders 5, 390-396

Parchmann CJ, McBride JM (2011). Relationship between functional movement screen and athletic performance. Journal of Strength and Conditioning Research 25, 3378-3384

Peate WF, Bates G, Lunda K, Francis S, Bellamy K (2007). Core strength: a new model for injury prediction and prevention. Journal of Occupational Medicine and Toxicology 2, 1-9

Pontillo M, Spinelli BA, Sennett BJ (2014). Prediction of in-season shoulder injury from preseason testing in division I collegiate football players. Sports Health 6, 497-503

Prieske O, Muehlbauer T, Borde R, Gube M, Bruhn S, Behm DG, Granacher U (2016). Neuromuscular and athletic performance following core strength training in elite youth soccer: Role of instability. Scandinavian Journal of Medicine and Science in Sports 26, 48-56

Putnam CA (1993). Sequential motions of body segments in striking and throwing skills: descriptions and explanations. Journal of Biomechanics 26, 125-135

Reed CA, Ford KR, Myer GD, Hewett TE (2012). The effects of isolated and integrated 'core stability' training on athletic performance measures: a systematic review. Sports Medicine 42, 697-706

Reeves NP, Cholewicki J, Silfies SP (2006). Muscle activation imbalance and low-back injury in varsity athletes. Journal of Electromyography and Kinesiology 16, 264-272

Reeves NP, Narendra KS, Cholewicki J (2007). Spine stability: the six blind men and the elephant. Clinical Biomechanics 22, 266-274

Richardson CA, Jull GA, Hodges PW, Hides JA (1999). Therapeutic exercise for spinal segmental stabilization in low back pain: Scientific basis and clinical approach. Churchill Livingstone: Edinburgh p. 1-185

Saeterbakken AH, van den Tillaar R, Seiler S (2011). Effect of core stability training on throwing velocity in female handball players. Journal of Strength and Conditioning Research 25, 712-718

Saeterbakken AH, Andersen V, Jansson J, Kvellestad AC, Fimland MS (2014). Effects of BOSU ball(s) during sit-ups with body weight and added resistance on core muscle activation. Journal of Strength and Conditioning Research 28, 3515-3522

Saeterbakken AH, Fimland MS, Navarsete J, Kroken T, van der Tillaar R (2015). Muscle activity, and the association between core strength, core endurarnce and core stability. . Journal of Novel Physiotherapy and Physical Rehabilitation 2, 55-61

Sale D, MacDougall D (1981). Specificity in strength training: a review for the coach and athlete. Canadian Journal of Applied Sport Sciences 6, 87-92

Sell TC, Tsai YS, Smoliga JM, Myers JB, Lephart SM (2007). Strength, flexibility, and balance characteristics of highly proficient golfers. Journal of Strength and Conditioning Research 21, 1166-1171

Shultz R, Anderson SC, Matheson GO, Marcello B, Besier T (2013). Test-retest and interrater reliability of the functional movement screen. Journal of Athletic Training 48, 331-336

Silfies SP, Cholewicki J, Reeves NP, Greene HS (2007). Lumbar position sense and the risk of low back injuries in college athletes: a prospective cohort study. BMC Musculoskeletal Disorders 8, 1-7

Silfies SP, Ebaugh D, Pontillo M, Butowicz CM (2015). Critical review of the impact of core stability on upper extremity athletic injury and performance. Brazilian Journal of Physical Therapy 19, 360-368

Smith BE, Littlewood C, May S (2014). An update of stabilisation exercises for low back pain: a systematic review with meta-analysis. BMC Musculoskeletal Disorders 15, 1-21

Smith CE, Nyland J, Caudill P, Brosky J, Caborn DN (2008). Dynamic trunk stabilization: a conceptual back injury prevention program for volleyball athletes. Journal of Orthopaedic and Sports Physical Therapy 38, 703-720

Stanton R, Reaburn PR, Humphries B (2004). The effect of short term Swiss ball training on core stability and running economy. Journal of Strength and Conditioning Research 18, 522-528

Steffen K, Myklebust G, Olsen OE, Holme I, Bahr R (2008). Preventing injuries in female youth football--a cluster-randomized controlled trial. Scandinavian Journal of Medicine and Science in Sports 18, 605-614

Stevens VK, Coorevits PL, Bouche KG, Mahieu NN, Vanderstraeten GG, Danneels LA (2007). The influence of specific training on trunk muscle recruitment patterns in healthy subjects during stabilization exercises. Manual Therapy 12, 271-279

Stodden DF, Fleisig GS, McLean SP, Andrews JR (2005). Relationship of biomechanical factors to baseball pitching velocity: within pitcher variation. Journal of Applied Biomechanics 21, 44-56

Tate A, Turner GN, Knab SE, Jorgensen C, Strittmatter A, Michener LA (2012). Risk factors associated with shoulder pain and disability across the lifespan of competitive swimmers. Journal of Athletic Training 47, 149-158

Teyhen DS, Shaffer SW, Lorenson CL, Halfpap JP, Donofry DF, Walker MJ, Dugan JL, Childs JD (2012). The Functional Movement Screen: a reliability study. Journal of Orthopaedic and Sports Physical Therapy 42, 530-540

Tropp H, Ekstrand J, Gillquist J (1984). Stabilometry in functional instability of the ankle and its value in predicting injury. Medicine and Science in Sports and Exercise 16, 64-66

Tse MA, McManus AM, Masters RS (2005). Development and validation of a core endurance intervention program: implications for performance in college-age rowers. Journal of Strength and Conditioning Research 19, 547-552

van Beijsterveldt AM, van de Port IG, Krist MR, Schmikli SL, Stubbe JH, Frederiks JE, Backx FJ (2012). Effectiveness of an injury prevention programme for adult male amateur soccer players: a cluster-randomised controlled trial. British Journal of Sports Medicine 46, 1114-1118

Vibe Fersum K, O'Sullivan P, Skouen JS, Smith A, Kvale A (2013). Efficacy of classification-based cognitive functional therapy in patients with non-specific chronic low back pain: a randomized controlled trial. European Journal of Pain 17, 916-928

Walden M, Atroshi I, Magnusson H, Wagner P, Hagglund M (2012). Prevention of acute knee injuries in adolescent female football players: cluster randomised controlled trial. BMJ 344, e3042

Warren M, Smith CA, Chimera NJ (2015). Association of the functional movement screen with injuries in division I athletes. Journal of Sport Rehabilitation 24, 163-170

Watson AW (1999). Ankle sprains in players of the field-games Gaelic football and hurling. Journal of Sports Medicine and Physical Fitness 39, 66-70

Wedderkopp N, Kaltoft M, Lundgaard B, Rosendahl M, Froberg K (1999). Prevention of injuries in young female players in European team handball. A prospective intervention study. Scandinavian Journal of Medicine and Science in Sports 9, 41-47

White AA, Panjabi MM (1978). Clinical biomechanics of the spine. Lippincott, Williams and Wilkins. Philadelphia, p. 1-722

Whiteside D, Deneweth JM, Pohorence MA, Sandoval B, Russell JR, McLean SG, Zernicke RF, Goulet GC (2016). Grading the functional movement screen: A comparison of manual (real-time) and objective methods. Journal of Strength and Conditioning Research 30, 924-933

Willems TM, Witvrouw E, Delbaere K, Philippaerts R, De Bourdeaudhuij I, De Clercq D (2005). Intrinsic risk factors for inversion ankle sprains in females--a prospective study. Scandinavian Journal of Medicine and Science in Sports 15, 336-345

Willson JD, Dougherty CP, Ireland ML, Davis IM (2005). Core stability and its relationship to lower extremity function and injury. Journal of the American Academy of Orthopaedic Surgeons 13, 316-325

Zazulak BT, Hewett TE, Reeves NP, Goldberg B, Cholewicki J (2007a). The effects of core proprioception on knee injury: a prospective biomechanical-epidemiological study. American Journal of Sports Medicine 35, 368-373

Zazulak BT, Hewett TE, Reeves NP, Goldberg B, Cholewicki J (2007b). Deficits in neuromuscular control of the trunk predict knee injury risk: a prospective biomechanical-epidemiologic study. American Journal of Sports Medicine 35, 1123-1130

Zielinski KA, Henry SM, Ouellette-Morton RH, DeSarno MJ (2013). Lumbar multifidus muscle thickness does not predict patients with low back pain who improve with trunk stabilization exercises. Archives of Physical Medicine and Rehabilitation 94, 1132-1138

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