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Comparing lumbopelvic stabilization exercises and yoga on functional stability and low back pain in young, non-elite, female gymnasts

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Abstract

Background: It is beneficial for gymnasts to train key lumbopelvic musculature to decrease or prevent low back injury. This study compares lumbopelvic exercises and yoga on lumbar muscle endurance, lumbopelvic stabilization, abdominal strength and balance in adolescent female gymnasts and the effect on low back pain.

Material/Methods: 13 participants were randomly allocated to a lumbo-pelvic or yoga group intervention and performed specific exercises for 6 weeks. Biering-Sorensen Test, Lumbopelvic Control Test, Side Bridge Test, and Star Excursion Balance Test were conducted on the participants before and after the 6-week intervention and low back pain logbooks were completed.

Results: The Biering-Sorensen Test was significantly greater results for the lumbopelvic group compared to the yoga group. Both groups had significant changes over time with the Lumbopelvic Control Test but no group difference. Both groups had significant improvement with the Side Bridge with the yoga group benefitting more on the left. Out of the six fully completed logbooks, the yoga group showed less occurrence of low back pain compared to the lumbopelvic group.

Conclusions: Yoga and lumbopelvic stabilization exercises are equally effective in developing lumbar muscle endurance, lateral stability and front-on stability for young non-elite gymnasts. This is important as they are under-represented in research but over-represented in participation. This study sets the basis for further research on the incidence of low back pain in young gymnasts and the effects of age-appropriate exercises as a preventative matter.

Keywords: Core training, muscle endurtance, stablility Biering-Sorenson, Side Bridge, Lumbopelvic Control Test

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INTRODUCTION

In gymnastics, the body endures high amounts of repetitive twisting, rotating, and bending (Kolba, 2005). The sport involves a high level of skill as well as strength and flexibility, yet many sustain injury with the lower spine being a common site for acute and chronic overuse cases (Mulhearn, 1999). Injuries reported in gymnasts include anterior apophyseal ring avulsion, spondylolysis, spondylolisthesis, disc herniation, bone marrow edema (Bennett, 2006), endplate damages, fractures, disc degeneration, muscle strains, ligament sprains, and non-specific low back pain (Caine et al., 1989; Harringe et al., 2007; Harringe et al., 2004; Homer and Macintosh,1992; Katz and Scerpella, 2003; Sward et al., 1990; Sward et al., 1990).

The likelihood for a gymnast to acquire low back pain and injury is relatively high in comparison with other sports with annual incidences between 30-90% as well as frequently recurring incidence of 72% (Caine et al., 1989). Injury rates per 1000 exposures of female gymnasts range from 3.7 to 22.7 (Caine et al., 1989; Sands et al., 1993; Weiker, 1985). Women's U.S. collegiate gymnastics has the highest percentage low back injury rate of all the NCAA sanctioned and monitored sports (NCAA, 2004).

A potential factor in the etiology of low back injury and pain is weakness in the lumbar spine musculature around the lumbar region (Pareniapour et al., 1988). Controlling the spine is complex because it relies on well-coordinated muscles (Panjabi, 2006) specifically the transverse abdominis and abdominal obliques (Richardson et al., 1990). These two muscle groups have obtained special attention due to their importance for controlling movement and stability of the spine (Richardson et al., 1990). In the general athletic population, reduced trunk extensor muscle endurance is a risk factor for low back injury and resultant pain (Biering-Sorensen, 1984). Those with poor trunk muscle endurance, therefore, may have low muscle fatigue thresholds that could result in an increased loading of the passive low back structures such as bone, disc, and ligaments (Mayer et al., 1995; Wilder et al., 1996).

Reported risk factors for developing low back injury and pain in gymnasts include starting at a young age, training and competing during periods of growth (Kujala et al., 1997), complexity of skills performed (Dixon and Fricker, 1993), and overall duration of training along with the exposures of biomechanical force during the landing (Daly et al., 2001; Harringe et al., 2007).

One key aspect that may be effective in the prevention or reduction of low back injury is optimal stability in the lumbo-pelvic region. Bouisset (1991) proposed that stabilization of the pelvis and trunk is necessary for all movements of the extremities. Its stability is dependent on a combination of global, superficial muscles around the abdominal and lumbar region and local stability in the intrinsic muscles of the abdominal wall (Marshall & Murphy, 2005). For gymnasts, core stability training is vital due to inherent components such as spinning and rotation (Kolba, 2005) as these require complex interactions between skeletal, ligamentous, and muscular components (McGill et al., 2003).

Proper maintenance of balance and postural equilibrium is vital in sport (Riemann & Guskiewicz, 2000) so the focus of training should include muscular stabilization of abdominal, paraspinal, and gluteal muscles in order to provide better stability and control (Nadler et al., 2002). Therefore, it is not simply one element that needs to be trained, but numerous components including balance, proprioception, strength, and stability of the whole lumbo-pelvic region.

Several studies have measured the relationship of core stability and low back pain and exercise interventions incorporated into training in order to reduce or prevent the likelihood of low back injury, however, most have focused primarily on collegiate-level or elite adult and junior-level gymnasts. Thus, there exists a paucity of empirical evidence on the effectiveness of lumbo-pelvic stability on the adolescent level. Furthermore, those studies that have focused on junior-level participants have done so at the elite level. This is problematic as the majority of junior-level participants are not elite level and may not benefit from these interventions. Therefore, the primary aim of this study was to compare the effect of two, 6-week core stability interventions on lumbar endurance, lumbo-pelvic stabilization, abdominal strength and balance in non-elite level, young female gymnasts. A secondary aim was to examine the effectiveness of the 6-week core stability interventions on low back pain.

MATERIAL AND METHODS

Participants

Participants were recruited from a local gymnastics academy. Interested parents and participants were provided with a participant Health History Questionnaire, Parent Consent form, and Participant Consent form. Demographics on the Health History Questionnaire included age, height/weight, years of experience, previous/ current injuries, other sports and activities involved with, and history of low back injuries. The female gymnasts (n=13) ranged from ages 9-17 years old (Table 1) who practice approximately 3-5 days per week at 4 hours per session. All participants had parental consent forms signed in order to participate.

Table 1. Participant Demographics

Participants	# Participants	Age (yrs) (±) S.D.	Height (cm) (±) S.D.	Weight (kg) (±) S.D.
Lumbo-pelvic Group	6	12±2.9	58.2 ±4.9	91.6 ±30.3
Yoga Group	7	11.2 ±1.3	56.8 ±1.6	79.8 ±13.0
Total	13	11.6 ± 2.4	57.5 ± 3.8	85.7 ± 24.1

Measures

The instruments used for this study measure muscle endurance, strength, balance, and lumbopelvic stability. A self-administered daily logbook was included to track changes in low back pain.

Pre- and Post-intervention test Measures. The Biering-Sorensen Test, Side-bridge, Star Excursion Balance Test and, Lumbopelvic Control Test. The Biering-Sorensen Test assesses the endurance of the erector spinae muscles. Actions of these muscles include extending the vertebral column bilaterally and laterally flexing the vertebral column unilaterally which are components of a gymnasts' performance with backward (concentric) and forward (eccentric) bending motions. Lumbopelvic Control Test assesses the rectus and transverse abdominis muscles. When activated, these muscles help maintain a neutral position of the pelvis in order to decrease the pressure being placed on the spine. The Side Bridge engages primarily the obliques and quadratus lumborum muscles. Together they help with rotation, forward flexion, and back extension, actions required for flips, twists, or rotating movements. Balance is an important gymnastic component therefore the Star Excursion Balance Test (SEBT) was included to measure dynamic balance.

Low Back Pain Survey. At the end of each day, participants responded to a primary question consisting of a single question and depending on their response directed to answer two additional questions. The primary question was "Do you have or have you had back pain today?" If so, the participant was instructed to make a mark on the exact location of pain on a diagram of the body and rate the intensity of pain with a category-ratio scale from 0-10; 0 being no pain and 10 being worst pain. Those who indicated 'yes' were then asked, "What generated the pain and what did they do to get relief?" Harringe et al. (2007) used this survey in a study.

Exercise Interventions

Each training session took approximately 20 minutes and began after team warmup. There was two training sessions per week with exercises gradually progressed over a 6-week period. Participants were compliant if they attended at least 80% of the exercise sessions over the 6-week training period.

Lumbopelvic intervention. Five exercises from the Princeton University Pelvic Stabilization, Lateral Hip, and Gluteal Strengthening Program were used and included: double leg bridge; single leg bridge; side bend; side plank; and fire hydrants. Previous studies have incorporated individual components such as the side plank and bridging (Mills et al, 2005; Durall et al, 2009).

Yoga Intervention. The five yoga poses incorporated are for this age group (Bregel, 2013) and included the downward-facing dog, bridge, child's pose, happy baby, and rag doll.

Procedures for Collecting Data

Following IRB [16-0286] approval and consent, demographics and anthropometric measurements and the four pre-intervention tests were completed. Logbooks were provided two weeks prior to the commencement of the pre-intervention test assessments.

Following pre-intervention data collection, participants were randomized to a lumbopelvic (n=6) or yoga (n=7) intervention and notified on the first day of the intervention. The interventions were under the direct supervision of the primary investigators for approximately 20 minutes prior to practice but after each had participated in the team warmup. At weeks two and four, each participant was assessed on their progress of each on the specific intervention components. For example, a participants' ability to reach the intended level of repetitions and sets. At this time, the investigators determined whether the participant was able to progress, reduce their levels, or continued at the same amount of repetitions and sets. Upon completion of the six-week interventions, participants completed the post-intervention measurement testing. Furthermore, participants submitted their daily logbooks two weeks after the six-week intervention.

Statistical Analysis

The data from the pre- and post-measurement tests was entered into SPSS v23. Multiple independent sample t-tests were conducted to establish any differences between the groups for pre-test, post-tests, and pre- to post- gains with the Biering-Sorensen Test, Side Bridge, and Lumbopelvic Control. To further explore group effects, an ANCOVA was conducted for both the Biering-Sorensen Test and the Side Bridge in which the pre-test scores were used as covariates. A MANOVA was conducted for the Star Excursion Balance Test to compare groups at pre-test, post-test, and gains from the pre- to post-test on both right and left sides. In order to measure low back pain or change in low back pain, logbook data was analyzed to assess the percentage of LBP occurrence for each group and group member. Of the 13 participants, 6 log books were fully completed and these were used in the analysis.

RESULTS

Relationship between pre- and post-scores for the Biering-Sorensen Test did not reach statistical significance (b = 0.44, p = .24). No group difference was observed at the pre-test (p = .63). While no group difference was observed for the absolute post-test scores (p = .15), the difference scores from pre to post were statistically greater for the lumbopelvic group (MΔ = 22.0) compared to the yoga group (MΔ = 9.8) with t(11) = 2.04, p = .033 (using a directional test). Please refer to Table 2 and 3.

Table 2. T-Test, Biering Sorenson Test (BST), Lumbopelvic Control Test (LCT), Side Bridge (SB)

Variable	N	Mean	SD	*p*
BST (pre-test)				
LP group	7	26.38	9.41	0.22
Yoga	6	23.73	9.67	
BST (post-test)				
LP group	7	36.19	7.81	0.98
Yoga	6	45.77	13.95	
LCT (pre-test)				
LP group	7	0.71	0.49	0.29
Yoga	6	1.5	0.84	
LCT (post-test)				
LP group	7	1.86	1.07	0.92
Yoga	6	3	1.26	
Right SB (pre-test)				
LP group	7	30.19	14.93	0.68
Yoga	6	33.22	9.65	
Right SB (post-test)				
LP group	7	41.9	18.87	0.92
Yoga	6	42.96	17.77	
Left SB (pre-test)				
LP group	7	24.01	11.4	0.22
Yoga	6	33.41	14.92	
Left SB (post-test)				
LP group	7	46.83	11.63	
Yoga	6	46.61	22.28	0.98

P = ≤.05

To further explore possible group effects, an ANCOVA model was run in which the pre-test scores were used as covariates. In alignment with the previous result, statistically significant group differences were observed (standardized coefficient for yoga group effect: β = –0.58, p = .043). To keep the number of parameter estimates reasonable, the age variable was treated as an interval measure instead of an ordinal measure, though comparable estimates were obtained when the larger parameter models were employed. Neither age nor pre-test were significant measures, and the experience difference was evident between levels 1 (1-2yrs experience) and 2 (3-5yrs experience) [(p = .047)] and levels 1 and 3 (6+ yrs experience) [(p = .037).]

Relationship between pre- and post-scores for the Lumbopelvic Control Test was statistical significance (b = 0.96, p = .040). Group differences were observed at the pre-test (M1 = 1.5 & M2 = 0.7) with t(11) = 2.11, p = .029). No group difference was observed for the absolute post-test scores (p = .92), and the difference scores from pre- to post were not statistically different (p = .80). Please refer to Table 2 and 3.

Relationship between pre- and post-scores for the right Side Bridge was statistical significance (b = 0.93, p = .015). No group difference was observed at the pre-test (p = .68). No group difference was observed for the absolute post-test scores (p = .92), and the difference scores from pre to post were not statistically different (p = .80). Thus, it appears both groups were comparable at pre- and post-test and comparable in their gains over time. Please refer to Table 2 and 3.

Relationship between pre- and post-scores for the left Side Bridge was statistical significance (b = 0.99, p = .001). No group difference was observed at the pre-test (p = .22). While no group difference was observed for the absolute post-test scores (p = .98), the difference scores from pre to post were statistically greater for yoga group (MΔ = 22.8) compared to lumbopelvic group (MΔ = 13.2) with t(11) = –1.94, p = .039 (using a directional test). Please refer to Table 2 and 3.

To further explore possible group effects, an ANCOVA model was run in which the pre-test scores were used as covariates. In alignment with the previous result, statistically significant group differences were observed (standardized coefficient for yoga group effect: β = +0.34, p = .036—using a directional test). This indicates that the yoga group showed higher scores on the left Side Bridge post-test scores after accounting for their pre-test scores.

To assess the Star Excursion Balance Test scores, a MANOVA compared the groups at pre-test, post-test and gains from pre- to post-test on both right and left sides. The only statistically significant finding (at a significance level of 0.10) was a possible group difference at post-test on the left side (p = .052). However, with the small sample size, this finding needs to be treated with caution.

Six fully completed logbooks were analysed. Of the six logbooks, there were group differences in the occurrence of low back pain. The yoga group showed

Table 3. Paired-sample t-tests for the pre- to post change and paired-sample *p*-value (p (Δ)) and the correlation (*r*) and *p*-value (p(r)). Biering Sorenson Test (BST), Lumbopelvic Control Test (LCT), Side Bridge

Variables	Group	N	Mean	SD	p (Δ)	*r*	*p (r)*
BST	Pre	13	25.15	9.22			
BST	Post	13	40.60	11.67			
BST	Δ	13	15.45	12.10	0.001	0.35	0.244
LCT	Pre	13	1.07	0.76			
LCT	Post	13	2.38	1.26			
LCT	Δ	13	1.30	1.03	0.001	0.58	0.040
Side Bridge (right)	Pre	13	31.58	12.36			
Side Bridge (right)	Post	13	42.38	17.60			
Side Bridge (right)	Δ	13	10.79	13.32	0.013	0.66	0.015
Side Bridge (left)	Pre	13	28.34	13.47			
Side Bridge (left)	Post	13	46.72	16.56			
Side Bridge (left)	Δ	13	18.37	9.87	0.000	0.80	0.001

$P = \leq .05$

two participants with an absence of low back pain throughout the whole study while one showed an increase at weeks 3-6 and a decrease post study. For the lumbopelvic group, one showed a decline of low back pain throughout the study while two showed a slight increase over the time period.

DISCUSSION

The Biering-Sorensen Test and Side Bridge were two used to determine lumbar endurance. The results did not show statistically significant group change after the 6-week intervention with improvements seen in 12 of the 13 participants. However, those in the lumbopelvic group showed greater improvements from pre- to post-test scores in comparison to the yoga group. Furthermore, the lumbopelvic group showed a statistically greater change over time. Therefore, lumbopelvic stability training may be a better option in this age group for the development in muscle endurance of the erector spinae muscles.

A possible reason for the greater improvement in lumbopelvic group is the inclusion of the Sidebend, also known as the Side Bridge, and Side Plank. This maneuver can activate muscles of the posterior abdominal wall and back such as the lumbar erector spinae, a key endurance muscle (McGill et al., 1996; McGill, 1998). Similar to the results in the current study, Durall et al. (2009) incorporated the Side Bridge to influence muscle endurance on collegiate-level gymnasts. In their study, the results reported significantly higher endurance improvements. However, their intervention was over a 10-week time period and the age of the participants were older. This is an important distinction as the response to muscle endurance gains may be similar to those of strength as longer duration periods of training provide more time to make gains (Kraemer and Fleck, 2007; Kraemer et al., 2002). Additionally, the use of collegiate-age participants, as compared to the younger age group in the current study, may also be a factor. For example, although muscle endurance is targeted in the current study it is known that maximal muscle force is lower in the younger population than in adults, even when size-normalized to body mass (De Ste Croix et al., 1999; Lambertz et al., 2003).

The relationship between muscle endurance and low back pain is documented. Nicolaisen and Jorgensen (1985) found those who had never experienced low back pain are able to hold isometric endurance of the trunk extensor muscles, measured with the Biering-Sorensen Test, longer than those who had experienced low back pain. Similar findings from Hultman et al. (1993) found that those with chronic low back pain averaged shorter endurance hold times in comparison to those who had never experienced low back pain. This is noteworthy, as a few of the participants in the current study had endured low back pain prior to, during, and/or after the intervention. Therefore, if a participant was experiencing or had experienced low back pain the gains may have been negligible, at best.

The Side Bridge, Lumbopelvic Control and Star Excursion Balance tests assessed stability. The Side Bridge is ideal as it tests an aggregate of trunk and abdominal muscles as they work synchronously (McGill et al., 2003) such as the obliques and quadratus lumborum that are key for stabilizing. Leetun et al. (2004) found the collegiate female basketball and cross-country athlete's demonstrated significantly reduced Side Bridge capacity along with hip abduction and external rotation suggesting that hip and trunk weakness reduces the ability of females to stabilize the trunk.

In the current study, results from the right Side Bridge demonstrated no group differences at post-test or pre- to post indicating both groups were comparable at pre- and post-test and comparable in gains over time. Results from the left Side Bridge showed a statistically significant difference from pre- to post with the yoga group, suggesting those exercises influence the development of lateral core stabilizer endurance more so than the lumbopelvic exercises. Future research should assess how specific yoga possess, for example the prone bridge such as the one in this study, may influence endurance of the lateral stabilizers.

Interestingly, the results showing side dominance may be an area for future research. The exercise interventions were bilateral in structure and for the most part gymnastics is not a one-side dominant sport. However, gymnasts have a dominant side or direction to perform a skill and an attempt to train, or exercise, on the non-dominant side may have influenced the results. Additionally, since this side is less dominant in most individuals (Hepper et al., 1991), there may have been more room for improvement in comparison to the right side. Moreover, the length of time of the intervention may have also contributed. For example, in Durall et al. (2009) study, which used the Side Bridge test for assessing endurance levels following a 10-week exercise intervention, results showed significant, but equal, differences in the right and left Side Bridge. The current study, in comparison, was shorter allowing more time for improvement if there were initial side-to-side variations.

Stability in the lumbopelvic region was also assessed using the Lumbopelvic Control test. The results indicated significance difference between pre- and post-scores for both training groups suggesting that these interventions are equally effective for front-on stability. For both the lumbopelvic and yoga groups, all participants increased by at least one level. However, it should be noted this is on a 5 points scale; therefore, this must be interpreted with caution, as a possible ceiling effect, in which the participants in the yoga group may have shown more increase if they had started lower and comparable to the lumbopelvic group. Perrott et al. (2012) suggested that optimal muscle recruitment patterns are essential to attain and maintain stability and without these patterns, a lack of improvement during the Lumbopelvic Control test may have occurred. Therefore, endurance training which can increase stabilization effectively by specific recruitment of muscles in the lumbopelvic region (Carpes et al., 2008), should be a key component with young gymnasts.

Additional testing of stability and balance with the Star Excursion Test indicated a slight, but not significant, group difference on the left side. However, the sample size needs consideration when reviewing these results. The possible reasons for this dissimilarity could be comparable to that of the left Side Bridge increases. Hand and foot dominance was not obtained from the participants but it can be assumed that the majority are right foot dominant (Dargent-Paré et al., 1992) therefore there was more room for improvement on the left side. In a study by Filipa et al. (2010), soccer players assessed with the Star Excursion Balance Test had significant improvements after a neuromuscular training program. However, that intervention differed from the current study by including two, 45-minute lower extremity, and core stability-training sessions over an 8-week period.

The exercise interventions were low impact and focused on areas that, if deficient, would affect the development or further development of low back pain. However, the logbook analysis revealed mixed results. Some of the participants remained pain-free while others had an increase and/or decrease. Although a similar study had reported better results (Harringe et al., 2007) the control of the spine is complex and it is only possible to diagnose a small proportion of low back sufferers on a patho-anatomical basis (Albert, et al., 2008). Therefore, the cause of some of the participants' low back pain is undefined and this is problematic when incorporating an intervention aimed on one aspect of a multifactorial problem.

There were several limitations to this study and most notably a lack of control group and an insufficient number of participants to determine whether these results can be reliably interpretable. Another limitation was the incompletion of several logbooks. Of the 13 participants, only six were fully completed and assumed filled out truthfully. The 'ceiling effect' in the Lumbopelvic Control test is also a limitation. Finally, the age range of the participants were too broad as it compared nine-year-olds to older teens, however, a majority of similar studies have involved older populations with many being at the elite-level.

The focus on a younger and more vulnerable population defines the novelty of this current research project and provides a basis for further research. A majority of past research is in the collegiate or elite-level even though there are reported low back issues starting as early as 9 or 10 years old. This study incorporated yoga with a view to measure its effect to commonly used core strengthening exercises. This is important, as further research needs to develop age-specific protocols geared towards younger gymnasts whose bodies are still in the developmental stages.

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REFERENCES

1. Albert HB, Kjaer P, Jensen TS, et al. Modic changes, possible causes and relation to low back pain. *Med Hypothesis*, 2008; 70: 361–368
2. Bennett DL, Nassar L, Delano MC. Lumbar spine MRI in the elite-level female gymnast with low back pain. *Skeletal Radiol*, 2006; 35(7): 503-509
3. Biering-Sorensen FA. Prospective study of low back pain in a general population. Occurrence, recurrence and aetiology. *Scand J Rehabil Med*, 1983; 15: 71–79
4. Bouisset S. Relationship between postural support and intentional movement: biomechanical approach. *Arch. Int. Physiol. Biochem. Biophys*, 1991; 99: 77–92.
5. Bregel S. Yoga for children, 2013. Available at:http://www.sheknows.com/parenting/articles/1009803/yoga-poses-for-kids; accessed 02.12.2016
6. Caine D, Cochrane B, Caine C. An epidemiologic investigation of injuries affecting young competitive female gymnasts. *Am J Sports Med*, 1989; 17: 811–820
7. Carpes FP, Reinehr FB, Mota CB. Effects of a program for trunk strength and stability on pain, low back and pelvis kinematics, and body balance: A pilot study. *J Bodywork Move Ther*, 2008; 12(1): 22-30
8. Daly R, Bass S, Finch C. Balancing the risk of injury to gymnasts: how effective are the counter measures? *Brit J Sports Med*, 2001; 35: 8–20
9. Dargent-Paré C, De Agostini M, Mesbah M, Dellatolas G. Foot and eye preferences in adults: relationship with handedness, sex and age. *Cortex*, 1992; 3: 343–351
10. De Ste Croix MBA, Armstrong N, Welsman JR. Concentric isokinetic leg strength in pre-teen, teenage and adult males and females. *Biol. Sport*, 1999; 16: 75–86
11. Dixon M, Fricker P. Injuries to elite gymnasts over 10 yr. *Med and Sci Sport Exer*, 1993; 25: 1322–1329
12. Durall CJ, Udermann BE, Johansen DR, et al. The effects of preseason trunk muscle training on low-back pain occurrence in women collegiate gymnasts. *J Strength Cond Res*, 2009; 23(1): 86-92
13. Filipa A, Byrnes R, Paterno MV, et al.Neuromuscular Training Improves Performance on the Star Excursion Balance Test in Young Female Athletes. *J Orthop Sports Phys Ther*, 2010; 40(9): 551-558
14. Harringe ML, Lindblad S, Werner S. Do team gymnasts compete in spite of symptoms from an injury? *Br J Sports Med*, 2004; 38: 398–401
15. Harringe ML, Nordgren JS, Arvidsson I, Werner S. Low back pain in young female gymnasts and the effect of specific segmental muscle control exercises of the lumbar spine: A prospective controlled intervention study. *Knee Surg Sport Tr*, 2007; 15(10): 1264-1271
16. Harringe ML, Renstrom P, Werner S. Injury incidence, mechanism and diagnosis in top level team gym. A prospective study conducted over one season. *Scand J Med Sci Sports*, 2007; 17: 115–119
17. Hepper PG, Shahidullah S, White R. Handedness in the human fetus. *Neuropsychologia*, 1991; 29: 1107–1111
18. Homer S, Mackintosh S. Injuries in young female elite gymnasts. *Physio*, 1992; 78: 804–808
19. Hultman G, Nordin M, Saraste H, Ohlsen H. Body composition, endurance, strength, cross-sectional area, and density of mm erector spinae in men with and without low back pain. *J Spine Disord*, 1993; 6: 114-123
20. Katz DA, Scerpella TA. Anterior and middle column thoracolumbar spine injuries in young female gymnasts. Report of seven cases and review of the literature. *Am J Sports Med*, 2003; 31: 611–616
21. Kolba C. *Getting to the Core. Tech*, 2005; Mar: 6-7
22. Kraemer WJ, Fleck SJ. Progressive Overload, Optimizing Strength Training: Designing Nonlinear Periodization Workouts. *J Hum Kinet*, 33–36; 2007
23. Kraemer WJ Adams K, Cafarelli E, Dudley GA, et al.American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sport Exerc*, 2002; 34(2):364–380
24. Kujala U, Taimela S, Oksanen A, Salminen J. Lumbar mobility and low back pain during adolescence. *Am J Sport Med*, 1997; 25: 363–368
25. Lambertz D, Mora I, Grosset JF, Perot C. Evaluation of musculotendinous stiffness in prepubertal children and adults, taking into account muscle activity. *J Appl Physiol*, 2003; 95: 64–72
26. Leetun DT, Ireland ML, Willson JD, et al.Core stability measures as risk factors for lower extremity injury in athletes. *Med Sci Sport Exerc*.2004 36: 926-934
27. Marshall PW, Murphy BA. Core stability exercises on and off a Swiss ball. *Arch Phys Med Rehab*, 2005; 86: 242–249
28. Mayer T, Gatchel R, Betancur J, Bovasso E. Trunk muscle endurance measurement. Isometric contrasted to isokinetic testing in normal subjects. *Spine*, 1995; 20: 920–927

29. McGill S, Juker D, Kropf P. Quantitative intramuscular myoelectric activity of the quadratus lumborum during a wide variety of tasks. *Clin Biomech*, 1996; 11: 170-172
30. McGill SM. Low back exercises; evidence for improving exercise regimens. *Phys Therapy*, 1998; 78: 754-765
31. McGill SM, Grenier S, Kavcic N, Cholewicki, J. Coordination of muscle activity to assure stability of the lumbar spine. *J Electromyogr Kines*, 2003; 13: 353-359.
32. Mills JD, Taunton JE, Mills WA. The effect of a 10-week training regimen on lumbo-pelvic stability and athletic performance in female athletes: A randomized-controlled trial. *Phys Ther Sport*, 2005; 6(2): 60-66
33. Mulhearn S, George K. Abdominal Muscle Endurance and its Association with Posture and Low Back Pain. *Physio*, 1999; 85(4): 210-216
34. Nadler SF, Malanga GA, Bartoli LA, et al. Hip muscle imbalance and low-back pain in athletes: influence of core strengthening. *Med Sci Sport Exer*, 2002; 34(1): 9-16
35. NCAA Injury Surveillance System Summary. In: NCAA Sports Medicine Handbook (2004-2005). Indianapolis, Ind: *National Collegiate Athletic Association*. 2004, 99–108.
36. Nicolaisen T, Jorgensen K. Trunk strength, back muscle endurance and low back trouble. *Scand J Rehabil Med*, 1985; 17: 121–127
37. Panjabi MM. A hypothesis of chronic back pain: ligament subfailure injuries lead to muscle control dysfunction. *Eur Spine J*, 2006; 15: 668–676
38. Parnianpour M, Nordin M, Kahanovitz N, Frankel V. The triaxial coupling of torque generation of trunk muscles during isometric exertions and the effect of fatiguing isoinertial movements on the motor output and movement patterns, *Spine*, 1988; 13: 982
39. Perrott MA, Pizzari T, Opar M, Cook J. Development of Clinical Rating Criteria for Tests of Lumbopelvic Stability. *Rehab Res Prac*, 2012
40. Richardson CA, Topperberg R, Jull GA. An initial evaluation of eight abdominal exercises for their ability to provide stabilization of the lumbar spine, *Aust J Physio*, 1990; 36: 6-11
41. Riemann BL, Guskiewicz KM. Proprioception and Neuromuscular Control in Joint Stability. *J Hum Kinet*, 37-51; 2000
42. Sands WA, Schultz BB, Newman AP. Women’s gymnastics injuries. A 5-year study. *Am J Sports Med*, 1993; 21: 271–276
43. Sward L, Hellstrom M, Jacobsson B, Peterson L. Back pain and radiologic changes in the thoraco-lumbar spine of athletes. *Spine*, 1990; 15: 124–129.
44. Sward L, Hellstrom M, Jacobsson B, et al.Disc degeneration and associated abnormalities of the spine in elite gymnasts. A magnetic resonance imaging study. *Spine*, 1991; 16: 437–443
45. Weiker GG. Injuries in club gymnastics. *Phys Sportsmed*, 1985; 13: 63–66
46. Wilder DG, Aleksiev AR, Magnusson ML, et al.Muscular response to sudden load: a tool to evaluate fatigue and rehabilitation. *Spine*, 1996; 21: 2628–2639