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| Subtopic | Author(s) | Type of Study | Methods | Results | Conclusions |
| Trunk/Core Contribution | Ellenbecker et al, 2004 | Cross sectional design-54 male, mean age 24.3 years-55 female, mean age 18.8 years-Subjects were free from back or pelvic injury-No injuries in the past year prior to testing-Ranked and/or competitive at junior, collegiate or professional level | Bilateral trunk strength was measured using Cybex Torso Rotation with an isokinetic dynamometer and medicine ball test1. Cybex Isokinetic Dynamometry2. Functional Medicine Ball Test | Symmetrical trunk rotation strength and endurance in males.- Slightly greater trunk rotation strength and endurance in backhand direction of females-Correlation b/w medicine ball test and isokinetic dynamometry | -Conditioning program for tennis players should target all segments of the body including the core musculature to avoid injury and improve performance |
| Plyometric Training | Behringer et al, 2013 | Randomized Controlled Trial-36 male, mean age 15.03 years-Subjects excluded if CVD, metabolic disorder, or recent msk injury present | . Traditional Resistance – using weight machines2. Plyometric Training – Plyometric Exercise\*both groups trained 2 days/wk+reg. tennis training1. Serve Velocity Testing2. Serve Precision Testing3. 10 RM Testing | -Improvements of the mean service velocity were significantly greater in PG when compared with CG values. -Only subjects in the PG made significantly greater gains in mean service velocity when compared to the control group. -10 RM values were significantly greater than pretest values in both the RG and PG. -10 RM values were added to a compound strength value for all participants - and these results demonstrated that subjects with greater increases in 10 RM also demonstrated greater increases in service velocity. | -These discussed exercises should be implemented into the design of conditioning programs for tennis juniors-Tennis specific plyometric are effective in improving tennis serve velocity in juniors |
| Strengthening | Ferrauti et al, 2007 | Cross sectional design-7 male and 6 female, 11-13 years | -Serve velocity and precision were observed after a specific intervention – either heavy, light, or controlled (for every subject in the study)1. Serve Velocity Testing2. Serve Precision Testing | -Heavy ball throwing intervention causes slight acute decrease in serve velocity | -There was no positive effect of either intervention protocol in this study with regard to service velocity and precision improvement |
| Strength Training | Treiber et al, 1998 | Randomized Controlled Trial-12 male, 13 female college players (age not stated)-No players reported history of shoulder injury in dominant arm-No acute shoulder injury, none participating in formal upper body or shoulder strengthening training for previous 6 months | Shoulder resistance group – 3x/wk for 4 weeks following tennis practice (only dominant arm)-2 sets of 20 reps, IR and ER exercises with dumbbell and therabandControl – Only regular tennis training1. Serve Velocity Testing2. Isokinetic Dynamometry | Resistance training with theraband and dumbbells increases IR and ER shoulder rotation torque and service velocity | Sports med professionals can incorporate these exercises into sport-specific tennis conditioning to improve performance and prevent injury |
| Biomechanics/Pathomechanics | Elliot et al, 2003 | Cross-sectional design-Subjects not specified, 36 matched analyzed-no inclusion or exclusion criteria and no specific subject population | 36 matches analyzed over 78 day period by video analysis to identify serve techniques used by tennis players1. Serve Velocity2. Shoulder ER angle3. Knee flexion angle4. Shoulder force and torque5. Elbow force and torque6. Shoulder IR torque7. Elbow extension angle8. Racket moment of inertia | -Dominant UE joints are subject to high loads during service motion and this repetitive motion can lead to overuse injury-Subjects with smaller leg drive loaded the shoulder and elbow with larger torque-At maximal ER, there was significantly lower normalized internal rotation torque recorded by the group with a higher mean knee flexion (>10 front knee joint flexion) (15.9), when compared to the group with a lower mean knee flexion (5.8). The group with the larger knee flexion recorded a mean IR torque of 43.7 Nm, while the less effective group recorded a mean IR torque of 57.8 Nm – significantly higher. | Physical conditioning should encompass all segments of the body in the context of the principal of the kinetic chain-More research needs to address training programs that target all segments of the body to understand effect on shoulder and elbow loading during serve performance |
| Trunk/Core Contribution | Chow et al, 2003 | Cross-sectional EMG analysis-5 male, mean age 19 years-Highly skilled players used as they demonstrated more consistent muscle activation patterns than beginners | -EMG analysis to monitor L and R RA, EO, IO, and ES activity during the tennis serve1. EMG values of L and R RA, EO, IO, and ES – measured as % of maximal isometric contraction | -Lower trunk muscles are involved in the tennis service motion-Eccentric contraction activity is prevalent in the lower trunk mm. during the tennis serve | -Strength and rehab programs should highlight the importance of abdominal and low back exercises to improve performance and decrease injury-Eccentric training is strongly recommended |
| Biomechanics/Pathomechanics | Martin et al, 2013 | Case Control study-11 male professionals, mean age 25.5 years-7 advanced amateurs, mean age 25.3 years-No reported shoulder injury, medical examination was performed prior to testing, all “considered healthy”- Pros had an ITF ranking, amateurs were classified based on ITF regulation criteria | Assessed joint kinetics and stroke production efficiency for shoulder, elbow, and wrist during tennis serve. Compared pros and amateurs.1. Post-impact ball velocity2. Serve efficiency testing3. Joint Kinetic values (joint forces, joint torques, moment of inertia) at shoulder, elbow, and wrist (16 peak joint kinetics) | Amateurs demonstrate lower ball velocity but similar or higher normalized UE joint kinetics versus pros. Advanced amateurs may be prone to higher risk of shoulder overuse injuries at the shoulder more so than the elbow and wrist | Sports med professionals can use this information to educate amateur tennis players about serve technique and the potential for overuse injury related to excessive shoulder joint loading-Biomechanics of movement patterns should be identified and potentially changed depending on MOI |
| Biomechanics/Pathomechanics | Kibler et al, 2007-16 male, 18-40 years old-Subjects with a history of shoulder problems, occult or overt instability, RC tendinitis, or other shoulder pathology were excluded.-Rated as 4.5-6.5 on National Tennis Rating program | Cross-sectional EMG study | EMG study to calculate onset and offset timing of scapulohumeral muscle activity patterns.1. EMG values – each muscle “on” when 3 SD points above baseline, “off” when dropped below 3 SD points. Duration of “on” time also measured. | “onset/offset” method demonstrated that scapular and shoulder muscles are activated in specific patterns during the tennis serve. | Conditioning and rehab programs need to incorporate these activation sequences, differential activation, and specific duration in order to enhance treatment and performance. –Not just about strength, but also about muscle coordination. |
| Strength Training | Nodehi-Moghadam et al, 2013. | Non-random Case-Control Study-15 throwing athletes, 15 non-athletes-Mean of 5.53 years of throwing experience-All subjects had no history of trauma, msk and neuro disorders, previous shoulder surgery and any UE or spine abnormality.-Control group was age, height, weight, and sex matched, with the same inclusion and exclusion criteria but no history of overhead sport | -Strength of shoulder rotational movements was tested with hand held dynamometer-IR and ER ranges were measured with standard goniometer-Ability of subjects to replicate the target position and kinesthetic sense was examined by using CPM device | -No significant difference in IR ROM between throwing athletes and non-athletic subjects.-ER ROM was significantly more in athletic subjects.-Throwing athletes demonstrate higher isometric strength of shoulder ER and IR than the non-athletic group-Throwing athletes demonstrate lower isometric strength of shoulder ER versus IR-Higher joint position acuity in throwing athletes versus non-athletes | Repetitive nature of overhead throwing and the high forces that it causes result in adaptive changes of the dominant extremity.Throwing can lead to mobility, strength, and neural adaptations. |
| Altered LT Relationships | Cools et al, 2007. | Case- Control study69 subjects – 39 overhead athletes (26 male, 13 female) WITH shoulder pain from various overhead sports: tennis, volleyball, swimming; 30 overhead athletes (19 male, 11 female) with NO history of shoulder injuries-Mean age was 22.5 years-Rowe score used to assess their functional ability | EMG activity of upper, middle, and lower trapezius was measured during isokinetic abduction and external rotation using surface electrodes in both the shoulder pain and healthy groups | There is a significant increase of upper trapezius activity during both movements in the patient group, with decreased activity in the lower trapezius during abduction, and in the middle trapezius during ER.-Intramuscular ratios revealed muscle imbalance on the injured side of the patient group for upper/middle and upper/lower trapezius during abduction and for all three muscle activity ratios during ER. | -The results demonstrate the presence of scapular muscle imbalances in patients with impingement symptoms and emphasize the relevance of restoration of scapular balance in shoulder rehabilitation. |
| Plyometric Training | Carter et al, 2007. | Randomized Controlled Trial-24 Division I collegiate male baseball players (age: 19.7 +/- 1.3 years; height: 183.9 +/- 5.9 cm; mass: 90.7 +/- 10.5 kg)-Subjects were rank-ordered based on concentric IR strength and were assigned randomly to a plyo group (PLY) or control group (CON). | Throwing velocity, isokinetic peak torque, isokinetic functional strength ratios, and time to peak torque were measured pre- and post-training.-Training consisted of 6 UE plyometric (“Ballistic Six”) exercises performed 2x/week for 8 weeks.-No plyo exercises for CON group but performed regular off-season S&C activities | -PLY demonstrated significant increases in throwing velocity following 8 weeks compared to CON.-No statistically significant differences in any of the isokinetic strength measurements between groups.-Statistically significant differences were seen within PLY for concentric IR and eccentric ER isokinetic strength at 180 degrees/sec and 300 degrees/sec. | -“Ballistic Six” plyometric training protocol can be a beneficial supplement to a baseball athlete's off-season conditioning by improving functional performance and strengthening the rotator cuff musculature. |
| Strength Training | Niederbracht et al, 2008. | Pretest-posttest, 2 group design-12 female, 2 collegiate women tennis teams (6 females on each team) during preseason training-Two groups did not significantly differ in age, height, weight, playing experience, or USTA ranking as assessed by the team’s coaches.-None of the subjects had conducted any specific shoulder strength training 6 months prior to the study, had undergone shoulder surgery, or experienced any shoulder pain within the last year. | 1 group participated in a 5-week, 4x/week, shoulder ER muscle strength training program (as outlined by a study by Roetert et al).-Other team participated in a comparable preseason tennis training program, but did not include any upper body strength training-Effects of strength training program were evaluated by comparing pre and post-training data of 5 maximal eccentric ER followed by concentric IR contraction on an isokinetic dynamometer | -Shoulder strength training program significantly increased eccentric external total work without significant effects on concentric internal total work, concentric internal mean peak force, or eccentric external mean peak force. | -By increasing the eccentric external total exercise capacity without a subsequent increase in the concentric internal total exercise capacity, this strength training program potentially decreases shoulder rotator muscle imbalances and the risk for shoulder injuries to overhead activity athletes. |
| Kinetic Chain Concepts | Maenhout et al, 2010. | Single group repeated-measures design-32 physically active individuals in “good general health” without history of neck and/or shoulder injury or surgery nor participated in high-level overhead sports or performed upper limb strength training for more than 5h/week. | -EMG activity measurement during UT, MT, LT and some SA during exercises-MVIC was recorded for each muscle-Subjects performed the standard KPP and six variations which included: one-handed KPP, KPP with ipsilateral leg extension, KPP with contralateral leg extension, KPP on wobble board, KPP with ipsilateral leg extension and wobble board, and KPP with contralateral leg extension and wobble board. | -Four exercises with a low UT/SA can be selected for rehab of intramuscular balance: standard KPP, KPP with ipsilateral leg extension, KPP with a wobble board and ipsilateral leg extension and one-handed KPP.-The use of the wobble board during KPP exercises and performance on one hand has no influence on SA EMG activity.-Contralateral leg extension during KPP stimulates LT activity, whereas ipsilateral leg extension stimulates SA activity. | In the presence of intramuscular scapular imbalance, some exercises are preferable over others because of their low UT/SA ratio. The use of a kinetic chain approach during KPP exercises influences scapular muscle activity. |
| Kinetic Chain Concepts | Fernandez et al, 2013. | Randomized Controlled Trial-30 competitive health and nationally ranked male junior tennis players-Subjects randomly and equally divided into control and training groups.-No players in study had regular experience in strength training-Minimum of 3 years of prior tennis-specific training-Inclusion criteria included healthy tennis player, no history of UE surgery, no shoulder pain for past 12 months, no rehab for past 12 months, and no participation in a formal strength-training program the 4 weeks before the study | -Study examined effects of 6-week strength-training program on throwing velocity in elite junior tennis players-Strength-training program was performed 3x/week for 6 weeks and included a combination of core, elastic tubing and medicine ball exercises that targeted muscles that are activated during the tennis serve-Control group participated in only tennis-specific training-Measurements included: maturity status, shoulder IR/ER ROM, first serve velocity analysis and radar specifications, serve accuracy | -Significant improvement in serve velocity for the training group after the intervention-Serve accuracy was not affected in the training group nor the control group-Shoulder IR/ER ROM significantly improved in both groups | The results demonstrated that a short-term training program for young tennis players, using minimum equipment and effort, can result in improved tennis performance (i.e. tennis serve velocity) and a reduction in the risk of a possible overuse injury, reflected by an improvement in shoulder ER/IR motion |
| Kinetic Chain Concepts | Scher et al, 2010. | Cross-sectional study-57 professional baseball players (29 pitchers, 28 field payers)-Participants were excluded from the study if they had shoulder pain or hip pain at the time of ROM measurements-All throwers practiced or played (or both) a min of 3x/week. | Outcome measures consisted of hip extension and IR, shoulder IR and ER, GIRD, and history of shoulder injury.-Differences in shoulder and hip ROM were assessed with a 1-way ANOVA.-Associations between hip and shoulder ROM were assessed with linear regression. | Non-pitchers with a history of shoulder injury had more ER and less IR of the shoulder than non-pitchers with no history of shoulder injury.-GIRD was greater in both pitchers and non-pitchers with history of shoulder injury.-Relationship between dominant hip extension and shoulder ER was significant for pitchers with a history of shoulder injury and non-pitchers with a history of shoulder injury. | -Shoulder injury may be associated with specific measures of hip and shoulder ROM-Hip extension and shoulder ER may be related in baseball players with a history of shoulder injury-Additional research is needed to understand the specific mechanisms of shoulder injury in overhead athletes |
| Kinetic Chain Concepts | DeMey et al, 2012. | Descriptive Study-30 young, healthy overhead athletes-Exercise performance was standardized and individualized based on height, age, and body weight. | EMG activity study was utilized to analyze individual muscle activation of UT and LT muscle to investigate the influence of trunk and LE position or movement during eight variations of a scapular retraction exercise.-Exercises were performed in front of a pulley apparatus. | -An unipodal squat position on the contralateral leg increased trapezius muscle activation by 3.93% maximum voluntary isometric contraction compared to the conventional seated performance of the exercise. -No differences between phases were found and no exercise activated a particular muscle part (upper trapezius or lower trapezius) to a greater extent in comparison with other exercises since no two-way interactions were found | -All exercise variations may be useful in the early phases of scapular rehabilitation training because of their favorable trapezius muscle balance activation. -Standing in a squat position on the contralateral leg can result in a slight increase in trapezius muscle activation. -Future comparative effectiveness studies are needed to identify the long-term training benefits of these exercises. |
| Altered LT Relationships | Myers et al, 2005. | Descriptive Laboratory Study-21 throwing athletes, 21 control subjects | -Scapular position and orientation during scapular plane humeral elevation were assessed with electromagnetic tracking.-Scapular upward/downward rotation, internal/external rotation, anterior/posterior tipping, and elevation/depression were assessed. | -Throwing athletes demonstrated significantly increased upward rotation, IR, and retraction of the scapula during humeral elevation.-No differences in anterior/posterior tipping and elevation/depression were present | -The results demonstrate that throwing athletes have scapular position and orientation differences compared to non-throwing athletes-Throwers can develop chronic adaptation for more efficient performance of the throwing motion-Scapular position, orientation and movement in overhead athletes should be assessed as part of the evaluation of shoulder injuries |
| Endurance and Fatigue Concepts | Tripp et al, 2004. | Repeated Cross-Over Design-13 high-level collegiate baseball pitchers as subjects | -Joint position sense/proprioception testing during the pitching motion-Fatigue induced through “fatigue-protocol” which included pitching baseball at maximum velocity every 5 seconds until a point of “fatigue” was reached (>15 RPE) | -Significant increase in error for joint repositioning which indicated fatigue-induced effects on joint sense and proprioception (greatest error during “cocking” phase of pitch) | Functional fatigue program produced increased error in joint position sense and motion reproductionErrors in arm-cocking phase can be influential due to microinstabilities that are commonly present in this phase or position |
| Endurance and Fatigue Concepts | Joshi et al, 2011. | Single Group Pre-/Post-Test Cross Sectional Design-22 “healthy” subjects from various overhead sports: volleyball, swimming, baseball, tennis | -Surface EMG analysis of UT, LT, SA, and infraspinatus muscles-Initial MVIC was recorded for each of the above mm during D2 PNF pattern to analyze joint kinematics-Shoulder ER fatigue protocol was used to induce fatigue (when 25% below baseline MVIC) | -Decreased LT activity post-fatigue (4%)-Increased infraspinatus activity (4%) on descent secondary due to decrease in LT activity-Sig increase in upward rotation during ascending phase post-fatigue (3 degrees) | -Force couple between infraspinatus and LT demonstrated altered length tension relationship with shoulder ER fatigue-LT fatigue could cause altered GH axis of rotation which altered length-tension relationship of muscles (infraspinatus) |
| Endurance and Fatigue Concepts | Szucs et al, 2009. | Case Series Design-28 “healthy” subjects underwent randomized testing of dominant and non-dominant UE | -Fatigue protocol involved push-up plus in order to induce fatigue to SA m.-MVIC for SA, LT, UT was recorded-Subject performed scaption pre and post SA fatigue protocol | -Significant increase in UT activity during scaption-All muscles tested demonstrated >8% decline in activation during exercise | -The increase in UT activity can increase clavicle elevation and subsequent scapular upward rotation |
| Proprioception | Padua et al, 2004. | Randomized Controlled Trial-54 healthy individuals randomly assigned to 4 training groups (1 was a control group) | -5 week training groups were CKC, OKC, and PNF-Studied the effects of the 3 different training methods on shoulder rotation strength, active angle reproduction, single-arm dynamic stability, and functional throwing in health individuals | -The results of the study demonstrated that CKC exercises are effective in improving shoulder proprioception and neuromuscular control in healthy individuals through the facilitation of shoulder muscle co-activation. -OKC exercises improved proprioception and neuromuscular control through enhancement of joint-position awareness.-Eccentric shoulder rotation strength increases were greatest in the OKC (20% increase in eccentric torque) and PNF (15% increase) versus the CKC (8.5% increase) group | -These findings depict CKC, OKC, and diagonal movement patterns may be effective in increasing scapular muscle and rotator cuff musculature activation which is an important component to overheard athletic activity, and therefore should be implemented into a conditioning program for tennis players. |
| Proprioception | Witt et al, 2011. | Single group repeated-measures design-21 healthy subject with no history of scapulohumeral dysfunction, population of convenience  | EMG analysis in which surface electrodes were applied to the SA, UT, MT and LT and EMG data collected for each muscle as the subject performed resisted UE D1 flexion, UE D1 extension, UE D2 flexion and UE D2 extension with elastic resistance and a three pound weight. | -The activity of the SA remained relatively the same during all patterns. -The LT activity was significantly greater during D2 flexion with elastic resistance than during the D1 flexion and D1 extension with elastic resistance. -MT activity was significantly greater during D2 flexion with elastic resistance as compared to all other patterns except D2 flexion with a weight. -UT activity was significantly greater during flexion patterns than extension patterns. | -Abnormalities in glenohumeral rhythm and neuromuscular control of the upper trapezius, middle, trapezius, lower trapezius and serratus anterior muscles have been demonstrated in individuals with shoulder pain-Support the use of the D2 flexion pattern with either elastic or weight resistance in order to achieve the greatest activation of all three trapezius muscles as well as the serratus anterior-PNF techniques can promote efficient neuromuscular mechanisms and improve function secondary to improved flexibility, functionality and functional movement patterns, improved joint stability, and improved neuromuscular coordination |

**References:**

1. Ellenbecker, T, and Roetert P. An Isokinetic Profile of Trunk Rotation Strength in Elite Tennis Players. Medicine & Science in Sports & Exercise. 2004; 36 (11): 1959-1963
2. Behringer M, et al. Effects of Two Differetn Resistance-Training Programs on Mean Tennis-Serve Velocity in Adolescents. Pediatric Exercise Science. 2013; 25: 370-384.
3. Ferrauti A, et al. Short-term effects of light and heavy load interventions on service velocity and precision in elite young tennis players. Br J Sports Med. 2007; 41: 750-753
4. Treiber F, et al. Effects of Theraband and Lightweight Dumbbell Training on Shoulder Rotation Torque and Serve Performance in College Tennis Players. Am J Sports Med. 1998; 26(4): 510-515
5. Elliot B, et al. Technique Effects on Upper Limb Loading in the Tennis Serve. Journal of Science and Medicine in Sport. 2003; 6(1):76-87
6. Chow J, et al. Lower trunk muscle activity during the tennis serve. Journal of Science and Medicine in Sport. 2003; 6(4):512-518
7. Martin C, et al. Upper limb joint kinetic analysis during tennis serve: Assessment of competitive level on efficiency and injury risks. Scand Jour Med Sci Sports. 2013; (Epub ahead of print)
8. Kibler W, et al. Muscle activation in coupled scapulohumeral motions in the high performance tennis serve. Br J Sports Med. 2007; 41:745-749
9. Nodehi-Moghadam A, et al. A Comparative Study on Shoulder Rotational Strength, Range of Motion and Proprioception between the Throwing Athletes and Non-athletic Persons. *Asian J Sports Med.* 2013;4(1):34-40.
10. Cools A, et al. Trapezius activity and intramuscular balance during isokinetic exercise in overhead athletes with impingement symptoms. *Scand J Med Sci Sports*. 2007;17:25-33.
11. Carter A, et al. Effects of high volume upper extremity plyometric training on throwing velocity and functional strength ratios of the shoulder rotators in collegiate baseball players. *J Strength Cond Res.* 2007;21(1):208-215.
12. Niederbracht Y, et al. Effects of a shoulder injury prevention strength training program on eccentric external rotator muscle strength and glenohumeral joint imbalance in female overhead activity athletes. *J Strength Cond Res.* 2008;22(1):140-145.
13. Maenhout A, et al. Electromyographic analysis of knee push up plus variations: what is the influence of the kinetic chain on scapular muscle activity? *Br J Sports Med*. 2010;44:1010-1015.
14. Fernandez J, et al. Effects of A 6-Week Junior Tennis Conditioning Program on Service Velocity. *Journal of Sports Science and Medicine*. 2013;12(2):232-239.
15. Scher S, et al. Associations among hip and shoulder range of motion and shoulder injury in professional baseball players. *J Athl Train*. 2010; 45(2):191-197.
16. DeMey K, et al. Kinetic chain influences on upper and lower trapezius muscle activation during eight variations of a scapular retraction exercise in overhead athletes. *J Sci Med in Sport.* 2012; 16: 65-70.
17. Myers J, et al. Scapular position and orientation in throwing athletes. *Am J Sports Med.* 2005; 33(2): 263-271.
18. Tripp B, et al. Functional fatigue decreases 3-dimensional multi-joint position reproduction acuity in the overhead-throwing athlete. *J Ath Train.* 2004; 39(4): 316-320.
19. Joshi M, et al. Shoulder external rotation fatigue and scapular muscle activation and kinematics in overhead athletes. *J Athletic Train.* 2011; 46(4): 349-357.
20. Szucs K, et al. Scapular muscle activation and co-activation following a fatigue task. *Med Biol Eng Comput.* 2009. 47(5):487-495.
21. Padua D, et al. The effect of select shoulder exercises on strength, active angle reproduction, single-arm balance and functional performance. *J Sport Rehabil*. 2004;13(1):75-95.
22. Witt D, et al. EMG of Scapular Muscles during Diagonal Patterns using Elastic Resistance and Free Weights. *Int J Sports Phys Ther.* 2011;6(4):322-332.