Systematic Review: *Effects of eccentric versus concentric exercise in stimulating gains in strength, hypertrophy, or performance in healthy adults.*

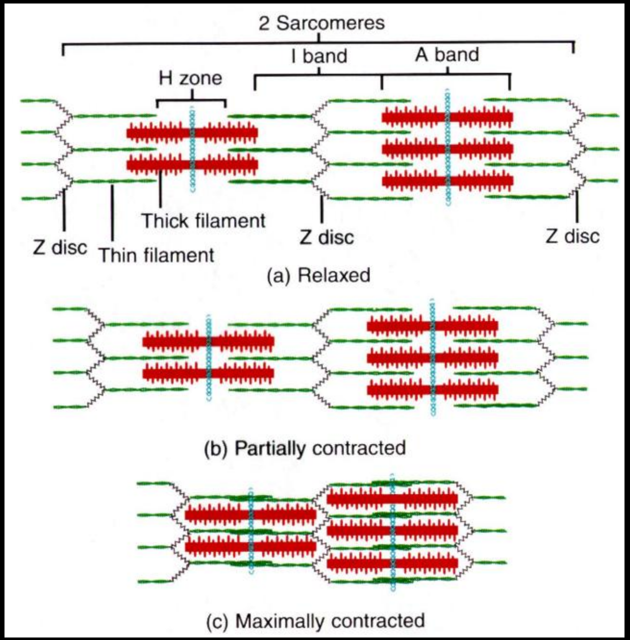
Presented by Gregory Kirk, Bob Maudie, Pat McKinnon, Ryan Murray, & Sarah Stewart

Introduction

- Resistance training is widely utilized by many facets of the population as a method of inducing gains in muscular strength
  - athletic performance
  - preventing injuries
  - improving functional capacity
  - maintaining a healthy lifestyle

Introduction: *Dynamic muscle activations*

- *Eccentric* = Dynamic muscle action which occurs when external resistance exceeds muscle force and the muscle lengthens while developing tension.
- *Concentric* = Dynamic muscle action which occurs when muscle shortens, and joint movement occurs as tension develops.



Introduction: *Eccentric vs. concentric activations*

- ↑'d ability to produce greater amounts of tension [3-5]
- ↓'d consumption of O_2 and ATP for a comparable workload [6-9]
- ↓'d EMG activation (ie. recruitment of a smaller motor unit pool) for a given tension [10]
- Smaller decreases in strength following repeated muscle contractions [2,11,12]
- Greater cross education [13]
- ↑'d muscle damage and delayed onset muscle soreness (DOMS) [14,15]

Introduction: *Potential benefits of eccentric activations*

- Potential for the development of greater strength gains, because the muscle can be overloaded to a greater extent [13,16,17]
  - Athletic performance, prevention of injuries, and a primary outcome measure
- Superior adaptations in muscular conditioning because of metabolic efficiency & decreased fatigability
  - Implications for older adults and clinical populations that have limited energy reserve

Systematic Review Question

- Is eccentric training superior to concentric training in stimulating gains in *muscular strength*, *hypertrophy*, and *performance* in healthy adults?


Methods

Methods: *Inclusion criteria*

- Healthy adult subjects (18 – 65 years)
- Resistance training program of at least 4 weeks in duration, minimum of 2x/week
- Testing and training completed on an isokinetic dynamometer
- Comparison of eccentric and concentric training programs
- Measurement of at least one of the following outcome measures: strength, hypertrophy, performance
- RCTs or CCTs in peer reviewed journals

Methods: *Exclusion criteria*

- Participants with any known existing pathological conditions
- Explored only one comparison variable (e.g. only eccentric training) *or* combined other interventions with eccentric and concentric programs
- Cross over design with insufficient washout period ($\leq$ 6 months)
- Non-English studies

Methods: *Search Strategy*

- Electronic searches were performed on the following databases: *SPORTDiscus, EMBASE, MEDLINE, CINAHL, PEDro, and Cochrane Controlled Trial Register.*
- Grey literature searches were conducted using Proquest, PapersFirst, and ProceedingsFirst.
- Hand searches were performed for the following journals from January 1997 to April 2007: Journal of Applied Physiology, British Journal of Sports Medicine, Sports Medicine, American Journal of Sports Medicine, and the Medicine Science of Sport and Exercise.
- Reference lists of included articles were screened using the same criteria as applied to the initial citation search.

Study selection

Potentially relevant publications identified and screened for retrieval.
N =1933

Papers excluded by title - unsuitable based on outlined criteria.
N = 1726

Publication abstracts retrieved for more detailed evaluation.
N = 208

Papers excluded by abstract - unsuitable based on outlined criteria.
N = 175

Publications (full text) articles retrieved.
N = 33

Publications excluded: N = 22
Not age appropriate:2
Did not meet minimum training duration/frequency: 2
No isokinetic dynamometer:7
Not an appropriate comparative outcome measures: 7
Insufficient washout period: 4

Publications included in the systematic review.
N = **11 FULL TEXT**

Methods: *Quality and Evidence assessment*

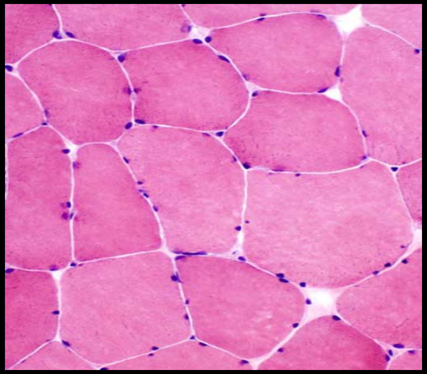
- *Quality assessment*
  - Modified Van Tulder ~ 11 point scale
  - Sackett's model was used to describe the level of evidence for each included study
  - Best evidence synthesis was used to describe the overall grade of evidence

Methods: *Data extraction*

- *Data extraction*
  - A data extraction form was developed to improve standardization and ease of the extraction process
  - Data extraction was completed by 2 reviewers independently for each full text publication
  - Disagreements were resolved during a consensus meeting.

Methods: *Data analysis*

- Data was analyzed qualitatively for the following comparisons:
    1. Effectiveness of eccentric versus concentric training on eccentric, concentric, and isometric strength
    2. Effectiveness of eccentric versus concentric training on selected hypertrophy measures
    3. Effectiveness of eccentric versus concentric training on selected performance measures


Results & Discussion

Results: *Study description*

Study	Quality score (Modified Van Tulder)	Study design	Level of Evidence
Duncan et al.[32]	3	RCT	2B
Ellenbecker et al.[39]	4	CCT	2B
Higbie et al.[33]	6	RCT	1B
Hortobagyi, Barrier, et al.[34]	4	RCT	2B
Hortobagyi, Hill et al.[2]	5	RCT	1B
Komi et al.[16]	3	RCT	2B
Mayhew et al.[35]	5	CCT	1B
Miller et al.[36]	7	CCT	1B
Mont et al.[40]	7	RCT	1B
Seger et al.[37]	4	CCT	2B
Tomberlin et al.[38]	4	RCT	2B

Results: *Study participants*

- *Training status:* Untrained (8), Moderately trained (1), Trained tennis players (2)
- *Sex:* Female only (3), Male only (5), Male and female (3)
- *Age:* Mean age = 24.0 years; Range 19.6 – 33 years
- *Dropout rate:* Reported by 7 studies
  ~ Mean = 1.4 subjects; Range 0 – 6 subjects

Results: *Training intervention*

- *Exercise:* Knee extension (7); Knee flexion and extension (1); Shoulder internal and external rotation (2); Elbow flexion (1)
- *Frequency:* Ranged from 2 – 4 days/week
- *Duration:* Ranged from 4 – 20 weeks, with 8/11 studies lasting between 6 – 10 weeks in length
- *Volume:* Ranged from 12 – 60 total exercise sessions; 1 – 8 sets of 6 – 12 repetitions (6 – 72 contractions per session)
- *Intensity:* Absolute (8) ~ MVC for both ETG and CTG; Relative (2) ~ ETG exercised at the same relative load as the CTG (90 – 100 % of the concentric MVC); "Submaximal" (1) ~ intensity not specified
- *Progression:* Periodization design (3), Constant number of sets and repetitions (8)
- *Contraction speed:* Varied from 60 – 210 deg/s; Single speed for all contractions (9); Pyramid of speed (2)


Strength

Results

Effectiveness of eccentric and concentric training on eccentric, concentric, and isometric strength

Results: *Strength*

- *Eccentric strength* ~ 10/11 studies measured eccentric strength in ETG and CTG
  - 9/10 studies found significant ↑’s with ET
  - 8/10 studies found significant ↑’s with CT
  - Of the 7 studies that compared the significance of the ET vs CT in producing gains in eccentric strength, all 7 found that ET improved eccentric strength significantly more than CT.

Results: *Strength*

- *Concentric strength* ~ 10/11 studies measured concentric strength in ETG and CTG
  - 6/10 studies found significant ↑'s with ET
  - 9/10 studies found significant ↑'s with CT
  - Of the 7 studies that compared the significance of the ET vs CT in producing gains in concentric strength, 2 found that CT improved concentric strength significantly more than ET. No studies found that the ET was significantly more effective than the CT in ↑'ing gains in concentric strength.

Results: *Strength*

- *Isometric strength* ~ 4/11 studies measured isometric strength in the ETG and CTGs
  - 2 studies found that isometric strength ↑ ‘d significant with ET; 1 study found that isometric strength ↑’d significant with CT
  - 2/4 studies did not report significance levels
  - 3 studies compared the significance of the ET vs CT in producing gains in isometric strength; mixed results were reported

Results: *Strength*

- *Total strength* ~ 2/11 studies calculated total strength gains by the ETG and CTG, averaging over all contraction types and velocities
  - No significant differences were reported
  - Three studies reported that the ETG ↑'d eccentric strength more than the CTG ↑'d concentric strength

Discussion

Effectiveness of eccentric and concentric training on eccentric, concentric, and isometric strength

Discussion: *Strength*

- *Eccentric strength*
  - Strong evidence that both ET and CT programs can produce gains in eccentric strength
  - Strong evidence that ET is superior to CT in developing eccentric strength
    - Suggests a strong mode specific relationship between ET and eccentric strength development

Discussion: *Strength*

- *Concentric strength*
  - Strong evidence that CT and ET programs are effective in producing gains in concentric strength
  - No evidence that CT is superior to ET in promoting concentric strength gains

Discussion: *Strength*

- *Isometric strength*
  - Indicative findings that both ET and CT are effective in producing gains in isometric strength
  - No evidence that either contraction type is superior

Discussion: *Strength*

- *Total Strength*
  - No evidence that either contraction type is superior in producing gains in total average strength
  - Strong evidence that ET increases eccentric strength more than CT increases concentric strength

Discussion: *Strength*

- *Eccentric vs Concentric*
  - Results clearly show that eccentric and concentric training are both effective methods of inducing strength gains in the healthy adult population
  - However, eccentric training appears to elicit a more substantial effect on mode specific strengthening
    - All studies that reported a statistical comparison of the ETG and CTG found that the ETG produced superior eccentric gains with respect to the CTG, but only two out of seven found that the CTG produced superior concentric gains in comparison to the ETG

Eccentric vs Concentric Cont.

- *Eccentric vs Concentric*
  - *The distinct outcomes generated by the eccentric and concentric training groups suggest that different mechanisms are responsible for increases in strength*
    - Eccentric muscle actions have been shown to generate significantly higher levels of maximal tension [3-5], it is possible that the greater increases in strength are due to the higher absolute loads
    - Two studies included addressed this issue by having the ETG and CTG exercise at equal absolute loads; the results were mixed

Eccentric vs Concentric Cont.

- Further research necessary, but results suggest that ET is potentially able to produce significantly greater eccentric gains than CT when exercising at equalized loads
- Suggests other adaptive mechanisms:
  - Combination of neurological factors and hypertrophy [2,32-34,38,42-45]


Hypertrophy

Results

Effectiveness of eccentric versus concentric training on selected hypertrophy measures

Results: *Hypertrophy*

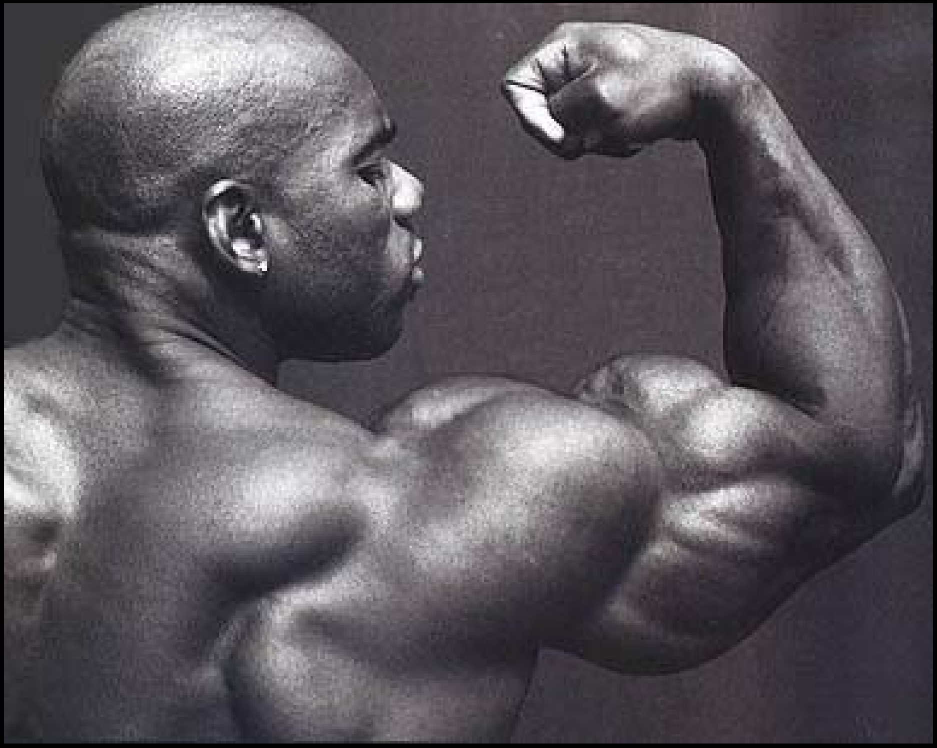
- 5/11 studies included a hypertrophy outcome measure
- 3 of which used measures of CSA
  - Duncan et al. reported no significant change in girth for eccentric or concentric training using a thigh circumference measure.
  - Komi et al. found a significant ↑ in upper arm circumference in the trained arm of the ETG compared to pre-test values and the CTG
  - Higbie et al., using MRI showed a significant ↑ in CSA in both ETG and CTGs with a significantly greater ↑ in the ETG compared to the CTG.

Results: *Hypertrophy*

- Two studies used muscle biopsies to explore changes fibre type and area.
  - Hortobagyi et al. showed no significant change in the percentage of type I fibres, a significant ↓ in type IIb fibres, and a significant ↑ in type IIa fibres in both the ETG and CTGs. They also showed a significant ten times greater ↑ in type IIa fibre area when comparing ETG to CTG.
  - Mayhew et al. showed no significant change in type I or type II fibres pre/post, but a significant ↑ in type II fibre area in the CTG compared to the ETG.

Discussion

Effectiveness of eccentric versus concentric training on selected hypertrophy measures



Discussion: *Hypertrophy*

- Moderate evidence that eccentric muscle training ↑’s skeletal muscle hypertrophy more than concentric training by measure of CSA
- Moderate evidence that eccentric training ↑’s type II fibre area greater than concentric training


Performance

Results

Effectiveness of eccentric versus concentric training on selected performance measures

Results: *Performance*

- 3/11 studies included performance measures
  - Two studies explored the effect of ET and CT on serve velocity.
    - Ellenbecker et al. → CT significantly ↑'d serve velocity compared to pre-test values. No significant change was seen in the ETG.
    - Mont et al. → ET and CT significantly ↑'d serve velocity compared to the CG.

      ~ Also explored % drop off of serve velocity → both training groups maintained serve velocity better than the CG. No difference between ETG and CTG.

Results: *Performance*

- Miller et al. included 2 performance measures:
  - *Acceleration time*
    - The CTG improved acceleration time, compared to pre-test values, for *concentric* knee extension only.
    - ETG had significant improvements in acceleration time for *concentric and eccentric* movements compared to the pre-test values. Improvements in acceleration time with eccentric movements were greater in the ETG compared to the CTG.
  - *Time to peak torque*
    - The CTG improved time to peak torque in *concentric* knee flexion and knee extension compared to pre-test values.
    - The ETG showed significant improvements for *concentric and eccentric* movements compared to the pre-test and also showed significant improvements in eccentric movements compared to the CTG.

Discussion

Effectiveness of eccentric versus concentric training on selected performance measures

Discussion: *Performance*

- *Serve velocity and endurance*
  - Limited evidence that both ET and CT improved serve velocity
  - Limited evidence that the ET and CT groups tended to maintain their serve velocity to a significantly greater extent than the CG
  - ET and CT → equally beneficial in improving serve velocity and endurance compared to a training regimen that does not include strength training

Discussion: *Performance*

- Acceleration time
  - Indicative finding → CT improved acceleration time, compared to pre-test values, for *concentric* knee extension only
  - Indicative finding → ET resulted in significant improvements in acceleration time for *concentric and eccentric* movements compared to the pre-test values
- Time to peak torque
  - Indicative finding → CT significantly improved time to peak torque in *concentric* knee flexion and extension compared to pre-test values
  - Indicative finding → ET resulted in significant improvements in *concentric and eccentric* movements compared to the pre-test and showed significant improvements in eccentric movements compared to the CTG
- Based on this single study, concentric training appears to be more mode specific compared to eccentric training in regards to these selected performance measures


Conclusion

Conclusion

- Eccentric and concentric strength training are effective means of producing gains in muscular strength in a population of healthy adults

- Eccentric training:
  - More effective than concentric strength training in stimulating gains in eccentric strength
  - ↑'s eccentric strength to a greater degree than concentric training ↑'s concentric strength

- Concentric training:
  - No evidence to support the superiority of concentric training in stimulating gains in concentric strength

Conclusion

- Hypertrophy:
  - Eccentric training ↑'d muscle fiber CSA more than concentric training and induced greater ↑'s in type II fiber area.
- Performance:
  - No significance difference in serve velocity
  - Indicative findings that both ET and CT improved acceleration time and concentric time to peak torque
  - Indicative evidence that ET was more effective at improving eccentric time to peak torque

Clinical implications

- Specificity: Target a specific muscle action to prevent injury of an athlete and enhance performance
  - Eccentric: Nordic hamstring curls in the training program of a sprinter
- Both modes should be considered when performance and injury prevention is the primary goal
- Eccentric training with energetically compromised populations may be warranted

Strengths

- Review limited to RCTs and CCTs
- Homogenous populations
- All training and testing completed on isokinetic dynamometers

Limitations

- Reviewers were not blinded to authors or journal publication
- Methodological weaknesses
  - Six studies of low quality (<5 mod VanTulder)
  - Four studies failed to report dropout rate
  - No allocation concealment or assessor blinding
- Restricted to studies written in English
- Main outcome measure focused on body structure and function level of ICF, minimal involvement on an activity or participation level
- Population of healthy adults: lacks external validity to the clinical population
- Isokinetic dynamometer not commonly used in clinical rehabilitation

Future Recommendations

- Reviews
  - Comparison of eccentric and concentric training at the same absolute load
  - Differences with fatigue and activation patterns using EMG between ETG and CTG
  - Isotonic actions as this contraction type relates more to the general population
  - Examining the effect of the combination of modes versus a single mode is warranted
- Research
  - More primary research is needed on the effects of resistance training and its application to performance

Acknowledgements

- The research was not funded by grants or sponsorship, and no relevant conflicts of interest existed for any of the authors
- Thanks to:
  - Darlene Reid: Supervisor
  - Angela Busch: RSPT 532 instructor
  - Charlotte Beck: assistance with research strategies
  - Susan Harris: RSPT 572 coordinator

Final cost of systematic review...

8 credits (RSPT 526, 532, and 572)	$5920.00
Transportation to meetings	$376.05
Phone calls	$478.12
Photocopying	$126.56
Printing	$267.89
Cutting edge Filing Device	$11.02
Surprise	
– Additional Administration Fees	$400 x 5

Completion of a Systematic Review ....


PRICELESS!

References

1. McCafferty WB, Horvath SM. Specificity of exercise and specificity of training: a subcellular review. Res Q 1977; 48: 358-71
2. Hortobagyi T, Hill JP, Houmard JA, et al. Adaptive responses to muscle lengthening and shortening in humans, J Appl Physiol 1996; 80 (3): 765-72
3. Crenshaw AG, Karlsson S, Styf J, et al. Knee extension torque and intramuscular pressure of the vastus lateralis muscle during eccentric and concentric activities. Eur J Appl Physiol 1995; 70: 13-19
4. Westing SH, Cresswell AG, Thortensson A. Muscle activation during maximal voluntary exercise and concentric knee extension. Eur J Appl Physiol 1991; 62: 104-08
5. Westing SH, Seger JY. Eccentric and concentric torque velocity characteristics, torque output comparisons and gravity effect torque corrections for the quadriceps and hamstring muscles in females. Int J Sports Med 1989; 10: 175-80
6. Bigland-Ritchie B, Woods JJ. Integrated electromyogram and oxygen uptake during positive and negative work. J Physiol 1976; 260: 267-77
7. Knuttgen HG, Bonde-Petersen F, Klausen K. Oxygen uptake and heart rate response to exercise performed with concentric and eccentric muscle contractions. Med Sci Sports 1971; 3: 1-5
8. LaStayo P, Reich TE, Urquhart M, et al. Chronic eccentric exercise: improvements in muscle strength can occur with little demand for oxygen. Am J Physiol 1999; 276: R611-15
9. Ryschon TW, Fowler MD, Wysong RE, et al. Efficiency of human skeletal muscle in vivo: comparison of isometric, concentric, and eccentric muscle action. J Appl Physiol 1997: 83: 867-74
10. Seger JY, Thortensson A. Muscle strength and myoelectric activity in prepubertal and adult males and females. Eur J Appl Physiol 1994; 69: 81-87
11. Hortobagyi T, Tracy J, Hamilton G, et al. Fatigue effects on muscle excitability. Int J Sports Med 1996; 17: 409-14
12. Tesch PA, Dudley GA, Duvosin MR, et al. Force and EMG signal patterns during repeated bouts of concentric and eccentric muscle actions. Acta Physiol Scand 1990; 138: 263-71
13. Hortobagyi T, Lambert NJ, Hill JP. Greater cross education following muscle lengthening than shortening. Med Sci Sports Exerc 1997; 29: 107-12
14. Stauber, WT. Eccentric action of muscles: physiology, injury, and adaptation. Exer Sport Sci Rev 1989; 17: 157-85
15. Friden J, Lieber RL. Eccentric exercise-induced injuries to contractile and cytoskeletal muscle fibre components. Acta Physiol Scand 2001; 171: 321-26

16. Komi PV, Buskirk ER. Effect of eccentric and concentric muscle conditioning
17. on tension and electrical activity of human muscle. Ergonomics 1972; 15(4): 417-34
18. Johnson BL. Eccentric and concentric muscle trainin for strength development. Med Sci Sports Exerc 1972; 4: 111-115
19. Stone MH, O'Bryant HS, McCoy L, et al. Power and maximum strength relationships during performance of dynamic and static weighted jumps. J Strength Cond Res 2003; 17(1): 140-7
20. Enoka RM. Strength training for exercise performance and rehabilitation. Scand J Med Sci Sports 2007; 17(1): 1
21. Gissis I, Papadopoulos C, Kalapotharakos VI, et al. Strength and speed characteristics of elite, subelite, and recreational young soccer players. Res Sports Med 2006; 14(3): 205-14
22. Wilkerson, G.B., Pinerola, J.J., Caturano, R.W. Invertor vs. evertor peak torque and power deficiencies associated with lateral ankle ligament injury. J Orthop Sports Phys Ther 1997; 26(2): 78-86
23. Brooks JH, Fuller CW, Kemp SP, et al. Incidence, risk, and prevention of hamstring muscle injuries in professional rugby union. Am J Sports Med 2006; 34(8): 1297-306
24. Gioftsidou A, Beneka A, Malliou P, et al. Soccer players' muscular imbalances: restoration with an isokinetic strength training program. Percept Mot Skills 2006; 103(1): 151-9
25. Hortobagyi T. The positives of negatives: clinical implications of eccentric exercise in old adults. J Gerontol Biol Sci Med Sci 2003; 58A: M417-18
26. Marsh AP, Miller ME, Saikin AM, et al. Lower extremity strength and power are associated with 400-meter walk time in older adults: The InCHIANTI study. J Gerontol A Biol Sci Med Sci 2006; 61(11): 1186-93
27. Alegre LM, Jiménez F, Gonzalo-Orden JM, et al. Effects of dynamic resistance training on fascicle length and isometric strength. J Sports Sci 2006; 24(5): 501-8
28. Aagaard P, Andersen JL, Dyhre-Poulsen P, et al. A mechanism for increased contractile strength of human pennate muscle in response to strength training: changes in muscle architecture. J Physiol 2001; 534 (Pt. 2): 613-23
29. Kawakami Y, Abe T, Kuno SY, et al. Training-induced changes in muscle architecture and specific tension. Eur J Appl Physiol Occup Physiol 1995; 72(1-2): 37-43
30. Meeteren J, Roebroeck ME, Stern HJ. Test-Retest reliability in isokinetic muscle strength instruments of the shoulder. J Rehabilitaion Med 2002; 34(2):91-95
31. Zhou S. Chronic neural adaptations to unilateral exercise: mechanisms of cross education. Exerc Sport Sci Rev 2000; 28: 177-84
32. Steultjens EMJ, Dekker J, Bouter LM, et al. Occupational Therapy for Rheumatoid Arthritis. Cochrane Database of Systematic Reviews 2007; 2
33. Duncan PW, Chandler JM, Cavanaugh DK, Johnson KR, Buehler AG. Mode and speed specificity of eccentric and concentric exercise training. JOSPT 1989; 11(2) 70-75
34. Higbie EJ, Cureton KJ, Warren GL, et al. Effects of concentric and eccentric training on muscle strength, cross-sectional area, and neural activation. J Appl Physiol 1996; 81(5): 2173-81
35. Hortobagyi T, Barrier J, Beard D, et al. Greater initial adaptations to submaximal muscle lengthening than maximal shortening. J Appl. Physiol 1996; 81(4): 1677-1682
36. Mayhew TP, Rothstein JM, Finucane SD, et al. Muscular adaptation to concentric and eccentric exercise at equal power levels. Med Sci Sport Exerc 1995; 27(6): 868-73

37. Miller LE, Pierson LM, Nickols-Richardson SM, et al. Knee extensor and flexor torque development with concentric and eccentric isokinetic training. Res Q Exerc Sport 2006; 77(1): 58-63

38. Seger JY, Thorstensson A. Effects of eccentric versus concentric training on thigh muscle strength and EMG. Int J Sports Med 2005; 26(1): 45-52

39. Tomberlin, JP, Basford, JR, Schwen, EE, et al. Comparative study of isokinetic eccentric and concentric quadriceps training. JOSPT 1991; 14(1): 31-36

40. Ellenbecker TS, Davies GJ, Rowinski MJ. Concentric versus eccentric isokinetic strengthening of the rotator cuff. Objective data versus functional test. Am J Sports Med 1988; 16(1): 64-9

41. Mont MA, Cohen DB, Campbell KR, et al. Isokinetic concentric versus eccentric training of shoulder rotators with functional evaluation of performance enhancement in elite tennis players. Am J Sports Med 1994; 22(4): 513-517

42. Lieber R. L. Skeletal Muscle Structure and Function: Implications for Rehabilitation and Sports Medicine. Baltimore: Williams & Wilkins, c1992

43. Raue U, Terpstra B, Williamson DL, et al. Effects on short-term concentric vs. eccentric resistance training on single muscle fiber MHC distribution in humans. Int J Sports Med 2005; 26: 339-43

44. Seger JY, Arvidsson B, Thortensson A. Specific effects of eccentric and concentric training on muscle strength and morphology in humans. Eur J Appl Physiol 1998; 79: 49-57

45. Carey Smith R, Rutherford OM. The role of metabolites in strength training: a comparison of eccentric and concentric contractions. Eur J Apl Physiol 1995; 71: 332-36

46. Vikne H, Refsnes PE, Ekmark M, et al.. Muscular performance after concentric and eccentric exercise in trained men. Med Sci Sport Exer 2006; 38: 1770-81

47. Folland JP, Williams AG. The adaptations to strength training : morphological and neurological contributions to increased strength, Sports Med 2007; 37(2): 145-68

48. Blazevich AJ, Gill ND, Deans N, et al. Lack of human muscle architectural adaptation after short-term strength training. Muscle Nerve 2007; 35(1): 78-86

49. Hather BM, Tesch PA, Buchanan P, et al. Influence of eccentric actions on skeletal muscle adaptations to resistance training. Acta Physiol Scand 1991; 143(2): 177-85

50. Booth FW, Thomason DB. Molecular and cellular adaptation of muscle in response to exercise: perspectives of various models. Physiol Rev 1991; 71(2): 541-85

51. Bruyere SM, VanLooy S, Peterson D. The International Classification of Functioning, Disability and Health: Contemporary Literature Overview. Educational Publishing Foundation.2005; 1-21

52. LaStayo PC, Woolf JM, Lewek MD, et al. Eccentric muscle contractions: their contribution to injury, prevention, rehabilitation, and sport. J Orthop Sports Phys Ther 2003; 33: 557-571

Search strategy: EMBASE

Search #	Search term	Results	Limiters
1	Eccentric.mp	4738	Search was limited to human, English language, and adult (18 - 64 years) at search # 13.
2	Concentric.mp	6190	
3	1 & 2	1458	
4	MeSH term "muscle strength"	13694	
5	MeSH term "hypertrophy"	2111	
6	MeSH term "muscle fatigue"	4730	
7	MeSH term "muscle contraction"	18736	
8	MeSH term "muscle training"	1900	
9	MeSH term "muscle mass"	4024	
10	MeSH term "refractory period"	1667	
11	MeSH term "relaxation time"	1692	
12	4 or 5 or 6 or 7 or 8 or 9 or 10	43500	
13	3 & 12	475	

Search strategy: SPORTDiscus

Search #	Search term	Results	Limiters
1	Eccentric.mp	1472	All searches were limited to "English"
2	Concentric.mp	1148	
3	1 & 2	757	
4	MeSH term "strength"	11435	
5	MeSH term "power"	2177	
6	MeSH term "strength training"	3375	
7	MeSH term "hypertrophy"	656	
8	MeSH term "muscle contraction"	5105	
9	4 or 5 or 6 or 7 or 8	20319	
10	9 & 3	547	

Search strategy: SPORTDiscus

Search #	Search term	Results	Limiters
1	Eccentric.mp	1472	All searches were limited to "English"
2	Concentric.mp	1148	
3	1 & 2	757	
4	MeSH term "strength"	11435	
5	MeSH term "power"	2177	
6	MeSH term "strength training"	3375	
7	MeSH term "hypertrophy"	656	
8	MeSH term "muscle contraction"	5105	
9	4 or 5 or 6 or 7 or 8	20319	
10	9 & 3	547	

Search strategy: EMBASE

Search #	Search term	Results	Limiters
1	Eccentric.mp	4738	Search was limited to human, English language, and adult (18 - 64 years) at search # 13.
2	Concentric.mp	6190	
3	1 & 2	1458	
4	MeSH term "muscle strength"	13694	
5	MeSH term "hypertrophy"	2111	
6	MeSH term "muscle fatigue"	4730	
7	MeSH term "muscle contraction"	18736	
8	MeSH term "muscle training"	1900	
9	MeSH term "muscle mass"	4024	
10	MeSH term "refractory period"	1667	
11	MeSH term "relaxation time"	1692	
12	4 or 5 or 6 or 7 or 8 or 9 or 10	43500	
13	3 & 12	475