# Jump Training: ¿Why and How?: an Exhaustive Review

## Biological Adaptations with Jump Training

Rodrigo Ramírez-Campillo
Department of Physical Activity Sciences
Research Nucleus in Health, Physical Activity and Sport
Laboratory of Measurement and Assessment in Sports (LabMED)
University of Los Lagos, Osorno, Chile

UNIVERSIDAD DE LOS LAGOS

# Bone Adaptations

## JT may implicate GRF up to 7 times body mass

**Mackay M, Schinkelshoek D, et al. Biomechanical analysis of drop and countermovement jumps. Eur J Appl Physiol Occup Physiol 1986; 54 (6): 566-73**


Bassey EJ, Ramsdale SJ. Increase in femoral bone density in young women following high-impact exercise. Osteoporos Int 1994; 4(2): 72-5.

Bassey EJ, Rothwell MC, Littlewood JJ, Pye DW. Pre- and postmenopausal women have different bone mineral density responses to the same high-impact exercise. J Bone Miner Res. 1998 Dec;13(12):1805-13.

Fuchs RK, Bauer JJ, Snow CM. Jumping improves hip and lumbar spine bone mass in prepubescent children: a randomized controlled trial. J Bone Miner Res 2001 Jan; 16 (1): 148-56.

Heinonen A, Sievänen H, Kannus P, Oja P, Pasanen M, Vuori I. High-impact exercise and bones of growing girls: a 9-month controlled trial. Osteoporos Int. 2000;11(12):1010-7.

Johannsen N, Binkley T, Englert V, et al. Bone response to jumping is site-specific in children: a randomized trial. Bone 2003 Oct; 33 (4): 533-9.

MacKelvie KJ, Khan KM, Petit MA, Janssen PA, McKay HA. A school-based exercise intervention elicits substantial bone health benefits: a 2-year randomized controlled trial in girls. Pediatrics. 2003 Dec;112(6 Pt 1):e447.

MacKelvie KJ, McKay HA, Petit MA, et al. Bone mineral response to a 7-month randomized controlled, schoolbased jumping intervention in 121 prepubertal boys: associations with ethnicity and body mass index. J Bone Miner Res 2002 May; 17 (5): 834-44.

Petit MA, McKay HA, MacKelvie KJ, Heinonen A, Khan KM, Beck TJ. A randomized school-based jumping intervention confers site and maturity-specific benefits on bone structural properties in girls: a hip structural analysis study. J Bone Miner Res. 2002 Mar;17(3):363-72.

Witzke KA, Snow CM. Effects of plyometric jump training on bone mass in adolescent girls. Med Sci Sports Exerc 2000 Jun; 32 (6): 1051-7.

Iuliano-Burns S, Saxon L, Naughton G, et al. Regional specificity of exercise and calcium during skeletal growth in girls: a randomized controlled trial. J Bone Miner Res 2003 Jan; 18 (1): 156-62.

MacKelvie KJ, Khan KM, Petit MA, et al. A school-based exercise intervention elicits substantial bone health benefits: a 2-year randomized controlled trial in girls. Pediatrics 2003 Dec; 112 (6) E447-52.

MacKelvie KJ, Petit MA, Khan KM, et al. Bone mass and structure are enhanced following a 2-year randomized controlled trial of exercise in prepubertal boys. Bone 2004 Apr; 34 (4): 755-64.

McKay HA, MacLean L, Petit M, et al. ''Bounce at the Bell'': a novel programof short bouts of exercise improves proximal femur bone mass in early pubertal children. Br J Sports Med 2005 Aug; 39 (8): 521-6.

Guadalupe-Grau A, Perez-Gomez J, Olmedillas H, Chavarren J, Dorado C, Santana A, Serrano-Sanchez JA, Calbet JA. Strength training combined with plyometric jumps in adults: sex differences in fat-bone axis adaptations. J Appl Physiol (1985). 2009 Apr;106(4):1100-11.

Gunter K, Baxter-Jones AD, Mirwald RL, et al. Jump starting skeletal health: a 4-year longitudinal study assessing the effects of jumping on skeletal development in pre and circum pubertal children. Bone 2008 Apr; 42 (4): 710-8.

Kato T, Terashima T, Yamashita T, et al. Effect of lowrepetition jump training on bone mineral density in young women. J Appl Physiol 2006 Mar; 100 (3): 839-43.

Weeks BK, Young CM, Beck BR. Eight months of regular in-school jumping improves indices of bone strength in adolescent boys and girls: the POWER PE study. J Bone Miner Res 2008 Jul; 23 (7): 1002-11.

Vainionpaa A, Korpelainen R, Leppaluoto J, et al. Effects of high-impact exercise on bone mineral density: a randomized randomized controlled trial in premenopausal women. Osteoporos Int 2005 Feb; 16 (2): 191-7.

# Effects of JT in Female Bone Health (BMC, BMD): From Childhood to Older Age

## Type of Study:

Review and meta Analysis.

## Subjects

Females (from childhood to older age participants)

## Methods:

Data base research from 2009 to 2015, English.
12 studies (from 973) meet inclusion criteria.

## Results:

Impact exercises + RT are a key combination to improve/maintain bone health in pre and postmenopausal females.
At childhood, bone health can be improved with brief training sessions (10-20 min), incorporating high impact jumps (applied in schools).

## Interpretation:

With a modification in the impact level according to age, JT exercises may positively affect bone health in females.

Xu J, Lombardi G, Jiao W, Banfi G.
Effects of Exercise on Bone Status in Female Subjects, from Young Girls to Postmenopausal Women: An Overview of Systematic Reviews and Meta-Analyses.
Sports Med. 2016 Feb 8. [Epub ahead of print]
Sport Biological Centre, China Institute of Sport Science, Beijing, China.

**50-100 jumps/session.**

**3 – 5 sessions/wk.**

**5 - 24 months.**

**1% – 8% increase bone mass/density in youths (> effect at younger ages).**

**1% - 4% in adults.**

**> Increase at some anatomical sites (i.e., femoral neck).**

**Increased mass, density, estructure (geometry), strength.**

**Effects last for longer periods (i.e., reduced detraining effect).**

# Muscle-Tendon Complex Adaptations

**Although there is no consensus among studies, usually adaptations (if they occur) take place after 6-15 weeks.**

**> Elongation of Achilles tendon and elastic energy accumulation + CMJ performance**

Kubo K, Morimoto M, Komuro T, et al. Effects of plyometric and weight training on muscle-tendon complex and jump performance. Med Sci Sports Exerc 2007 Oct; 39 (10): 1801-10.

**>Stiffness in Achilles tendon and accumulation-release of elastic energy.**
**> Jump performance.**

Wu YK, Lien YH, Lin KH, Shih TT, Wang TG, Wang HK. Relationships between three potentiation effects of plyometric training and performance. Scand J Med Sci Sports. 2010 Feb;20(1):e80-6.

**>29% stiffness in Achilles tendon + Muscular concentric-explosive performance**

Burgess KE, Connick MJ, Graham-Smith P, et al. Plyometric vs. isometric training influences on tendon properties and muscle output. J Strength Cond Res 2007 Aug; 21 (3): 986-9.

**Increased stiffness in plantar flexors and CMJ.**

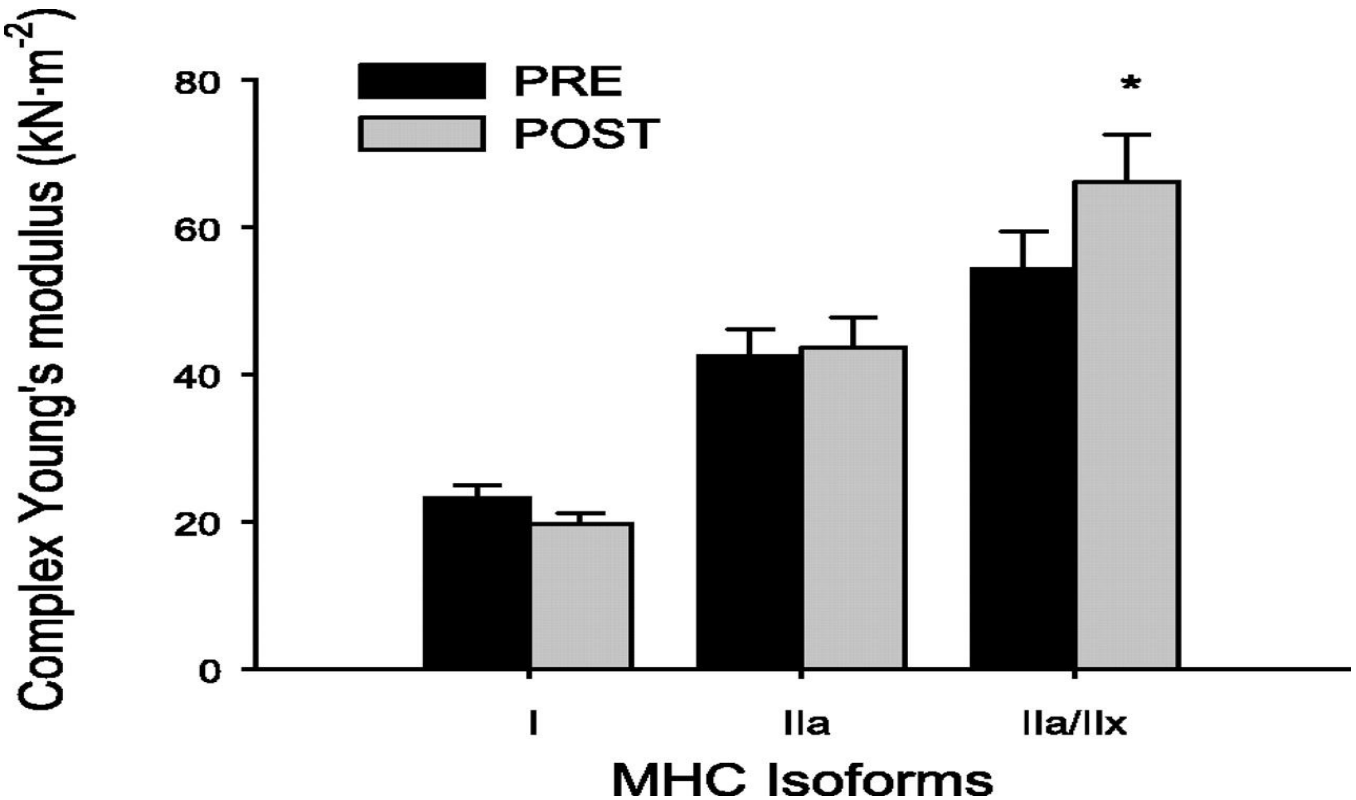
Pousson M, Lengrad J, Berjaud S, et al. Detente et elasticite: effets d'un entraımenent pliometrique. Sci Motric. 1995, 25 (1), 19-26.
Spurrs RW, Murphy AJ, Watsford ML. The effect of plyometric training on distance running performance. Eur J Appl Physiol 2003; 89 (1): 1-7

**Increased ankle stiffness.**

Cornu C, Almeida Silveira MI, Goubel F. Influence of plyometric training on the mechanical impedance of the human ankle joint. Eur J Appl Physiol Occup Physiol 1997; 76 (3): 282-8.

# Stiffness increase may be greater in fast muscle fibers.

Foure A, Nordez A, Guette M, et al. Effects of plyometric training on passive stiffness of gastrocnemii and the musculo-articular complex of the ankle joint. Scand J Med Sci Sports 2008; 19 (6): 811-8.




Malisoux L, Francaux M, Nielens H, Theisen D. Stretch-shortening cycle exercises: an effective training paradigm to enhance power output of human single muscle fibers. J Appl Physiol (1985). 2006 Mar;100(3):771-9.

# In addition, stiffness increase may be greater in bi-articular muscles (e.g. gastrocnemius).

Foure A, Nordez A, Guette M, et al. Effects of plyometric training on passive stiffness of gastrocnemii and the musculo-articular complex of the ankle joint. Scand J Med Sci Sports 2008; 19 (6): 811-8.

**Therefore…..**

**…..JT may induce adaptations in the muscle-tendon complex in the short-term.**

**Fast muscle fibers may achieve greater stiffness adaptations with JT.**

**However, performance increases is not always related to muscle-tendon complex adaptations.**

# Adaptations in Muscle Fiber Type

## Increased % of IIa in vastus lateralis.

Malisoux L, Francaux M, Nielens H, et al. Calcium sensitivity of human single muscle fibers following plyometric training. Med Sci Sports Exerc 2006 Nov; 38 (11): 1901-8.

## Combined with RT, an increase in Type IIa muscle fibers was observed in vastus lateralis.....

Perez-Gomez J, Olmedillas H, Delgado-Guerra S, et al. Effects of weight lifting training combined with plyometric exercises on physical fitness, body composition, and knee extension velocity during kicking in football. Appl Physiol Nutr Metab 2008 Jun; 33 (3): 501-10.

## ….however, several studies have reported contrasting results…..therefore, human studies are not conclusive.

## In animals (i.e., soleus rat muscle) seems to be consensus in that JT may increase the % of Type II muscle fibers.

# Muscle and Isolated Fibers Contractil Performance

**Type I, IIa y IIx: > maximal force, power and contraction velocity.**

**Whole muscle: > maximal force and power.**

Malisoux L, Francaux M, Nielens H, et al. Calcium sensitivity of human single muscle fibers following plyometric training. Med Sci Sports Exerc 2006 Nov; 38 (11): 1901-8.

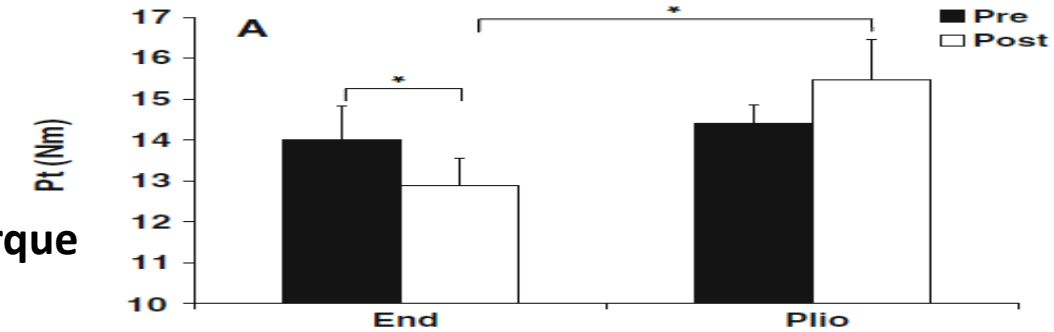
**Plantar flexors: < contraction time after 12 weeks.**

Kubo K, Morimoto M, Komuro T, et al. Effects of plyometric and weight training on muscle-tendon complex and jump performance. Med Sci Sports Exerc 2007 Oct; 39 (10): 1801-10.

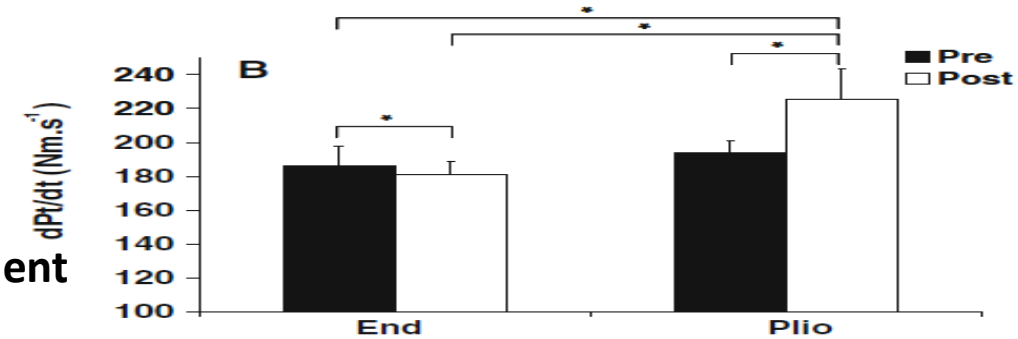
**Gastrocnemius: > maximal torque, RFD, and < contraction time after 10-wk.**

Grosset JF, Piscione J, Lambertz D, et al. Paired changes in electromechanical delay and musculo-tendinous stiffness after endurance or plyometric training. Eur J Appl Physiol 2009; 105 (1): 1673-83.

**Peak torque**




**Rate of torque development**



# Hipertrophy in Whole Muscle and Isolated Muscle Fibers

## Plantar flexors > volume (MRI) after 12-wk (similar increase compared to RT)

Kubo K, Morimoto M, Komuro T, et al. Effects of plyometric and weight training on muscle-tendon complex and jump performance. Med Sci Sports Exerc 2007; 39 (10): 1801-10.

## 8-wk of JT induced hypertrophy in vastus lateralis, in fibers type I (23%), type IIa (22%), and type IIa/IIx (30%).

Malisoux L, Francaux M, Nielens H, et al. Calcium sensitivity of human single muscle fibers following plyometric training. Med Sci Sports Exerc 2006; 38 (11): 1901-8.

## Vastus lateralis: increase in type I and type II muscle fibers (6% – 8%)

Potteiger JA, Lockwood RH, Haub MD, et al. Muscle power and fiber characteristics following 8 weeks of plyometric training. J Strength Cond Res 1999; 13 (3): 275-9.

## ….however, no changes were observed in gastrocnemius.

Kyrolainen H, Avela J, McBride JM, et al. Effects of power training on muscle structure and neuromuscular performance. Scand J Med Sci Sports 2005; 15 (1): 58-64.

# Mixed with RT.....

## .....no changes in females.....

Hakkinen K, Pakarinen A, Kyrolainen H, et al. Neuromuscular adaptations and serum hormones in females during prolonged power training. Int J Sports Med 1990; 11 (2): 91-8.

## .....but 20% increase in males (fast muscle fibers), with similar training.

Hakkinen K, Komi PV, Alen M. Effect of explosive type strength training on isometric force- and relaxation-time, electromyographic and muscle fibre characteristics of leg extensor muscles. Acta Physiol Scand 1985 Dec; 125 (4): 587-600.

## >4% in lean mass in lower body muscles (DEXA).

Perez-Gomez J, Olmedillas H, Delgado-Guerra S, et al. Effects of weight lifting training combined with plyometric exercises on physical fitness, body composition, and knee extension velocity during kicking in football. Appl Physiol Nutr Metab 2008 Jun; 33 (3): 501-10

## Mixed with endurance, vastus lateralis muscle fibers >6% – 7%

Potteiger JA, Lockwood RH, Haub MD, et al. Muscle power and fiber characteristics following 8 weeks of plyometric training. J Strength Cond Res 1999; 13 (3): 275-9.

**Therefore,**

**Moderate hypertrophy at short-term (8-12-wk) ¿long-term?**

**Hypertrophy in muscle fibers type I and type II, although greater in type II.**

**Lower hypertrophy effect compared to RT.**

**Greater hypertrophy in knee extensors vs. ankle extensors.**

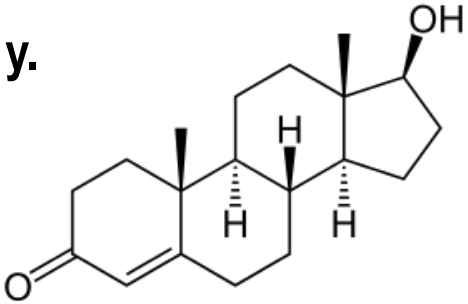
**Greater hypertrophy in males vs. females.**

**…..and these adaptations may be related with acute anabolic effects…..**

# Acute anabolic effects of JT in youths

**Type of study:** cross-sectional.

**Participants:** 26 male youth soccer players; age = 12-14 y.



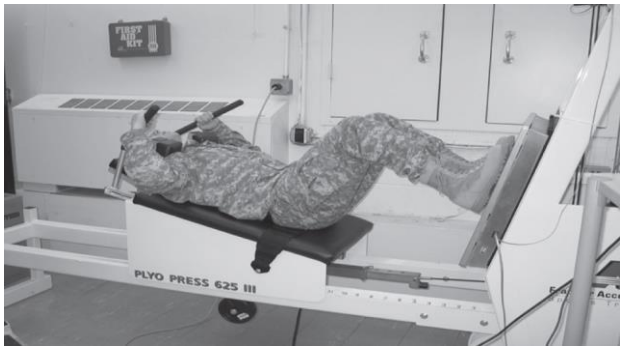

**Methods:** 2 randomized protocols (1-wk apart):
30 min RT vs. 30 min JT.

Saliva collected pre-control, post-control, 5 and 30 min post-exercise protocols.

**Results:** Testosterone increased at 5-min post RT (27% ± 5%) and JT (12% ± 6%).

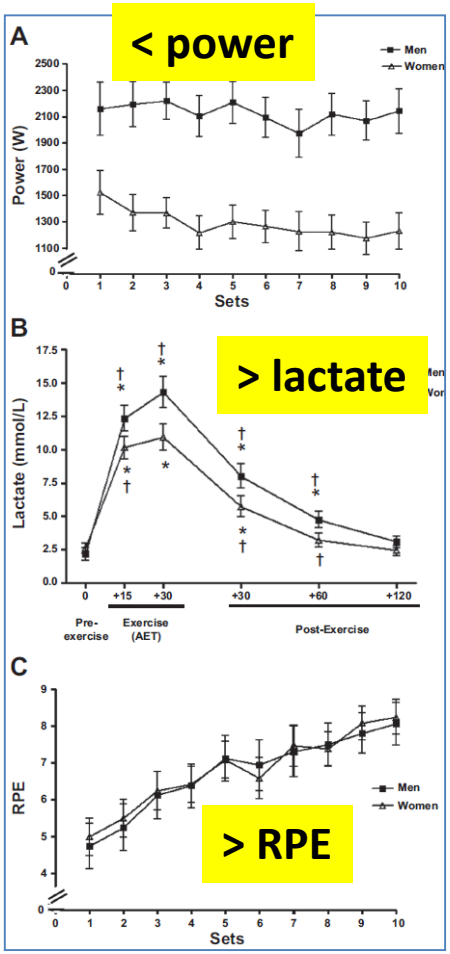
**Interpretation:** Although lower than RT, the transient anabolic effect of JT may favor a healthy growth, maturation and development process at youth ages.

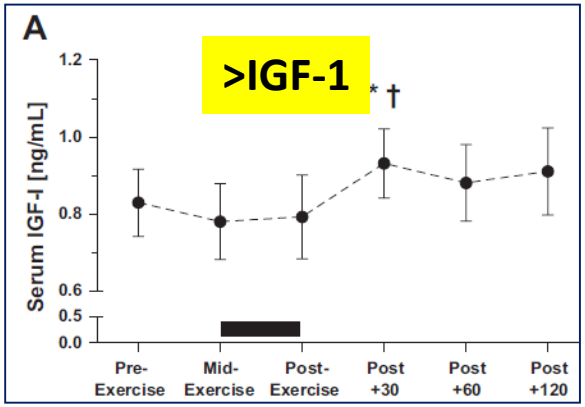
Klentrou P, Giannopoulou A, McKinlay BJ, Wallace P, Muir C, Falk B, Mack D.
Salivary cortisol and testosterone responses to resistance and plyometric exercise in 12- to 14-year-old boys.
Appl Physiol Nutr Metab. 2016 Mar 1:1-5. [Epub ahead of print]
Department of Kinesiology, Faculty of Applied Health Sciences, Brock University, St. Catharines, ON L2S 3A1, Canada.

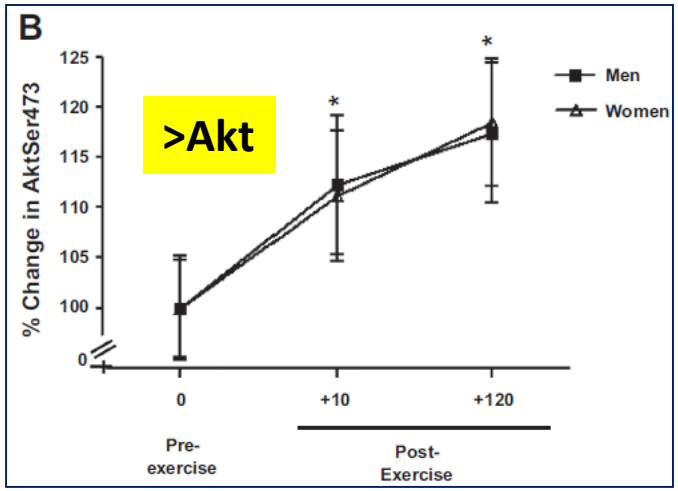


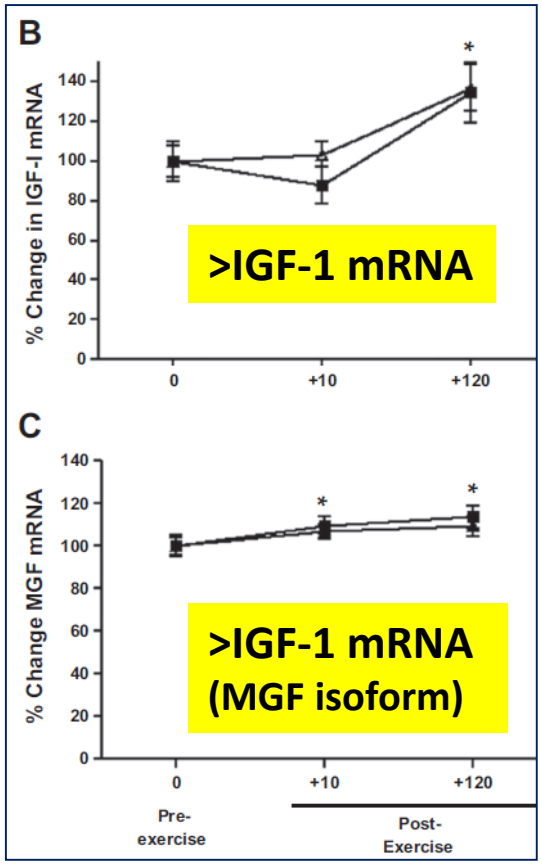

# Acute increase in IGF-1 after JT

**12 females and 8 males**
**100 jumps with 40% 1RM in sliding leg-press machine**
**10x10, 2-min of rest between sets.**




Nindl BC et al. IGF-I measurement across blood, interstitial fluid, and muscle biocompartments following explosive, high-power exercise. Am J Physiol Regul Integr Comp Physiol. 2012 Nov 15;303(10):R1080-9.

# Muscle Geometry

**Muscle geometry may affect muscle strength and power, and may be improved with training.**

**Blazevich AJ. Effects of physical training and detraining, immobilisation, growth and aging on human fascicle geometry. Sports Med 2006; 36 (12): 1003-17.**

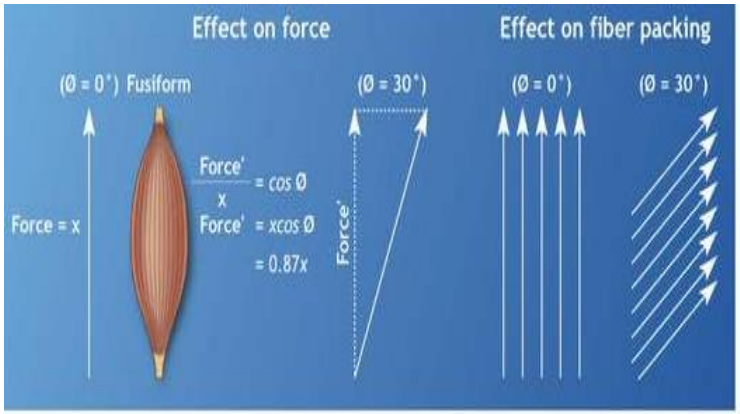



**Figure 18.4B.** Force development in a fusiform muscle with no angle of pennation (θ = 0°) and when θ = 30°. A 30° angle of pennation results in a 13% loss of each fiber's maximum force on the tendon, solely a result of muscle mechanics. However, pennation angle increases the number of fibers that pack into a given volume of muscle (bottom right). Muscle mass and the contractile capacity relate proportionately for a given muscle in comparisons among individuals. Because of the effect of pennation angle, however, it does not necessarily follow that muscle mass per se relates to an equivalent tension output in comparisons among different muscle groups. (Modified from Lieber RL. Skeletal muscle structure and function. Baltimore: Williams & Wilkins, 1992.)

**5-wk, JT + Sprint training**

**< angle and > length of fascicles in knee extensors + > physical performance.**

**Blazevich AJ, Gill ND, Bronks R, Newton RU. Training-specific muscle architecture adaptation after 5-wk training in athletes. Med Sci Sports Exerc 2003 Dec; 35 (12): 2013-22.**

# Neural Adaptations

## Isolated JT:

**Adductors: >pre-activation in DJ (intramuscular coordination).**
**Adductors and abductors: >co-activation in DJ (intermuscular coordination).**
**These adaptations may reduce injury risk.**

Chimera NJ, Swanik KA, Swanik CB, Straub SJ. Effects of Plyometric Training on Muscle-Activation Strategies and Performance in Female Athletes. J Athl Train. 2004 Mar;39(1):24-31.

**An 17% increase in maximal voluntary activation of calf muscles was observed.**

Kubo K, Morimoto M, Komuro T, et al. Effects of plyometric and weight training on muscle-tendon complex and jump performance. Med Sci Sports Exerc 2007; 39 (10): 1801-10.

**>MVC in calf muscles.**

Kyrolainen H, Avela J, McBride JM, et al. Effects of power training on muscle structure and neuromuscular performance. Scand J Med Sci Sports 2005; 15 (1): 58-64.

**> EMG activity in soleus muscle.**

Wu YK, Lien YH, Lin KH, Shih TT, Wang TG, Wang HK. Relationships between three potentiation effects of plyometric training and performance. Scand J Med Sci Sports. 2010 Feb;20(1):e80-6.

**Knee extensors >pre-activation during DJ performance.**

Kyröläinen H, Avela J, McBride JM, Koskinen S, Andersen JL, Sipilä S, Takala TE, Komi PV. Effects of power training on neuromuscular performance and mechanical efficiency. Scand J Med Sci Sports 1991; 1 (2): 78-87.

# Excitability changes in myotatic reflex.

Voigt M, Chelli F, Frigo C. Changes in the excitability of soleus muscle short latency stretch reflexes during human hopping after 4 weeks of hopping training. Eur J Appl Physiol Occup Physiol. 1998 Nov;78(6):522-32.

**Therefore, JT may induce both aferent and eferent neural adaptations.**

# JT combined with RT:

## >actividad muscular isométrica extensores de rodilla

**Hakkinen K, Komi PV, Alen M. Effect of explosive type strength training on isometric force- and relaxation-time, electromyographic and muscle fibre characteristics of leg extensor muscles. Acta Physiol Scand 1985 Dec; 125 (4): 587-600.**

**Hakkinen K, Pakarinen A, Kyrolainen H, et al. Neuromuscular adaptations and serum hormones in females during prolonged power training. Int J Sports Med 1990 Apr; 11 (2): 91-8.**

## >actividad muscular extensores de rodilla al saltar

**Hakkinen K, Komi PV. Effect of explosive type strength training on electromyographic and force production characteristics of leg extensor muscles during concentric and various stretch-shortening cycle exercises. Scand J Sports Sci 1985; 7 (2): 65-76.**

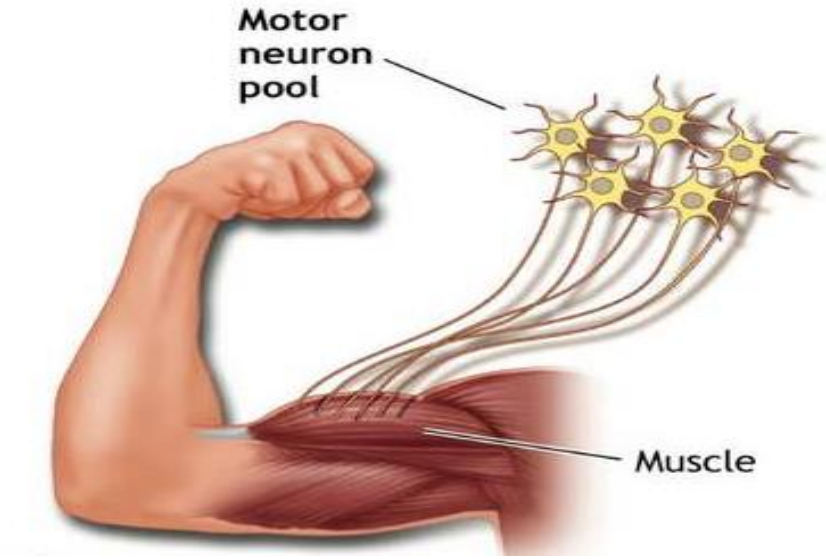
**Toumi H, Best TM, et al. Muscle plasticity after weight and combined (weight + jump) training. Med Sci Sports Exerc 2004; 36 (9): 1580-8.**

**Por tanto, el EP, aislado o combinado con RT puede > actividad muscular máxima (o voluntaria), sobre todo en flexores plantares.**

**El aumento podría explicarse por un > reclutamiento de UM o ritmo de disparo de estas (adaptaciones a nivel descendente).**

Moritani T. Neuromuscular adaptations during the acquisition of muscle strength, power and motor tasks. J Biomech 1993; 26, 1: 95-107.

Wu YK et al. Relationships between three potentiation effects of PT and performance. Scand J Med Sci Sports 2010;20(1):e80-6.




**El EP también podría modificar el patrón de reclutamiento muscular (i.e. coordinación intermuscular).**

**Los cambios de actividad muscular serían superiores al combinar EP + sobrecarga.**

Markovic G et al. Musculoskeletal and performance adaptations to lower-extremity plyometric training. Sports Med 40(10):859-895, 2010.

**La mayoría de las investigaciones han realizado EMG de superficie durante contracciones máximas o saltos.**

**Debido a que la EMG podría modificarse por cambios en el impulso neural central, hipertrofia, o incluso factores técnicos no fisiológicos, se debe tener cautela al analizar este tipo de estudios.**

Kamen G, Caldwell GE. Physiology and interpretation of the electromyogram. J Clin Neurophysiol 1996 Sep; 13 (5): 366-84.

**Futuros estudios en este ámbito deberían utilizar procedimientos de normalización EMG, técnicas de medición de UM aisladas y/o mediciones de respuestas reflejas inducidas (reflejo Hoffman, onda-F).**

Aagaard P. Training-induced changes in neural function. Exerc Sport Sci Rev. 2003 Apr;31(2):61-7.

# Sport Performance Adaptations

**Vertical jump....**
**.....Horizontal jump.....**
**.....Sprint.....**
**.....Agility.....**
**.....Endurance.....**
**.....Flexibility.....**
**.....Coordination.....**
**.....Strength.....**
**.....Power.....**
**.....Balance.....**

**These adaptations would be reviewed from specific sport-related interventions, including endurance, explosive, team and youth sports.....next week.**

# Review of the Day

# Adaptations Induced by JT

**Óseas**

**Stifness and complejo músculo-tendón**

**Tipología de fibras musculares esqueléticas**

**Rendimiento contráctil de fibras aisladas y músculo entero**

**Hipertrofia (¿producto de efecto anabólico post ejercicio?)**

**Geometría muscular**

## Adaptaciones neurales

## Adaptaciones rendimiento físico-deportivo

# Conclusiones referentes a la intensidad

**Existen pocos estudios experimentales referentes al análisis de la intensidad de ejercicios pliométricos.**

**Estos generalmente sugieren el uso de equipos como plataformas de fuerza y EMG para determinar la intensidad, lo cual es poco útil en ámbitos prácticos.**

**En estos estudios no se aclara cuales ejercicios son de “baja”, “moderada”, “alta”, etc……..intensidad.**

**La intensidad de algunos ejercicios se ha identificado como mayor o menor, dependiendo del parámetro usado para definir INTENSIDAD: RFD concéntrica, RFD excéntrica, fuerza concéntrica máxima, fuerza de impacto, fuerzas articulares (tobillo vs. cadera vs. rodilla), marcadores de daño muscular, EMG, etc.**

**Claramente este es un área que requiere de mayor investigación, para posteriormente iniciar intervenciones longitudinales.**