Original Article

Relationship of mechanical properties between vertical jump (SJ) and concentric test in a three angle isokinetic machine of lower extremities

XANTHOPOULOS NIKOLAOS¹, GISSIS IOANNIS¹, PAPADOPOULOS CHRISTOS¹, KOMSIS STERGIOS¹, BEKRIS EVANGELOS²

¹Sport Biomechanics Laboratory Department of Physical Education and Sport Sciences Serres, Aristotle University of Thessaloniki, GREECE

²National and Kapodistrian University of Athens, Department of Physical Education and Sport Sciences, GREECE

Published online: June 25, 2013

(Accepted for publication June 15, 2013)

DOI:10.7752/jpes.2013.02043;

Abstract

The purpose of this study was to evaluate the relationship of mechanical properties between vertical squat jump (SJ) and the concentric isokinetic test (Isokinetic Shortening Cycle) in three angle isokinetic dynamometer, where involved the total of kinematic chain of lower extremities (H-K-A), to check the possibility of using deliberate training loads. The sample was 18 students of Department of Physical Education & Sport Sciences (TEFAA, Serres), (age M=19,78years, sd=1,63, height M=178,06cm, sd=5,99 and weight M=74,42Kg, sd=8,54) without problems of wounds. The research took place in the Laboratory of Sport Biomechanics of TEFAA Serres of AUTH. For the methodology of measurement was used: a) Forceplate Kistler (type 9281CA), (frequency of sampling 1000Hz) β) Videocamera, type Panasonic AG-188 (frequency of sampling, 60f/sec). For the evaluation of kinematic, dynamic characteristics used the APAS system (Ariel Performance Analysis System). In order the results of correlation the test of ISSC could be considered as an appreciable test for the measurement of dynamic and power variables. Another one important application could appear to present in the process of training.

Keywords: Maximal force, Isokinetic, Concentric contraction, Squat jump (SJ), mechanical characteristics.

Introduction

Several researchers studied the reliability and validity of measurements in isokinetic dynamometers of self-made constructions, as well as in standard machines of various companies. Also measured the reliability of these devices through various parts of the body, such as i.e. upper & lower limbs, trunk, or several individual muscles and joints (Caiozzo et al. 1981; Martin et al. 1993; Lands et al. 1994; Wilson et al. 1997; Dowson et al. 1998; Blazevich and Jenkins 1998; Walshe et al. 1998; Kubo et al. 1999; Li et al. 1999 Paasuke et al. 2001; Gissis, 2003).

Vertical jump ability is an important and specialized form of training in many disciplines. Many researchers have addressed the plyometrics (Drop Jumps) and their research results offered a lot to the development of the coaching process (Bosco and Komi 1979). It has been shown the relationship of vertical jump capacity with high explosive capability. Jumps are compound movements, where achieved high reaction forces in conditions of high coordination of movement. The power is developed based on energy storage mechanism in elastic items, during the eccentric contraction and release during concentric (Steben and Steben, 1981; Bosco and Pittera, 1982; Clutch et al. 1983).

Literature suggests a specific set of performance testers vertical jump, which is the indicator of the jumping ability of the test (Garcia-lopez et al., 2005). This test package consists of the vertical jump from a standing position without swinging arms and the knees flexed 90° [Squat Jump (SJ)], the vertical jump with counter movement without swinging arms and upright [Counter Movement Jump (CMJ)] and the vertical jump performed after the body drop from a specific height [Drop Jump (DJ)], (Bosco et al., 1982; Liu et al., 2009; Pereira et al., 2009; Korff et al., 2009; Lazaridis et al., 2010). A stretch-shortening cycle (SSC) can be defined as an active stretch (eccentric contraction) of a muscle followed by an immediate shortening (concentric contraction) of that same muscle. In human skeletal muscle SSC gives unique possibilities to study normal and fatigued muscle function and it's found in most sports. Although explosive power has been extensively studied in lower body activities such as vertical jumping (Bosco et al., 1982; Tsatalas et al., 2010).

All kind of exercise including individual and team sports, share one common feature, that is the natural stretch and shortening cycle of eccentric-concentric, or concentric-eccentric contractions at sub maximal or maximal intensity. It is well known that during the eccentric phase of SSC, produced larger forces than the

concentric (Kues, Mayhew 1996, Enoka 1996). Although, experimental models of exercise with eccentric contractions are well documented in terms of the time course, the muscle damage, soreness and stiffness (Norrbrand 2008, Chapman 2007, Lavender 2006). or the protective effect against muscle damage (Chen 2007), much less is known about how mechanical and neural factors interact during exercise training with high intensity eccentric contractions close to 90% of the maximal eccentric force.

Eccentric programs are recognized as particularly effective in increasing maximal strength (Duclay et al. 2008). The development of isokinetic dynamometers allowed for application of an accommodating resistance to the muscles, resulting in eccentric exercise at a constant movement velocity. Schmidbleicher & Gollhofer (1982), argue that the differentiation of jump height in relation to the height of drop is a result to a technique modulation during performs the vertical jump. If the drop height increase and the technique of jumping is not brought under control, the participants are likely to make more traffic down the moment of landing. Bosco et al. (1979), argue that a depth of jump after falling height 20-40 cm high positive values observed in performance during the concentric phase of contraction, and when the jump is executed from greater heights, such as after a drop height of 40-60 cm, maximum values are observed both in the eccentric phase and in service during the concentric phase of contraction. Through the study of jumps conclusions are drawn for the level of reactive power. This provides information and for the SSC, but also for the use of elastic energy during this. Such information is provided by the index of the reaction force (IRF), which is used to determine the capacity of the muscular system to "react" with success on application requirements of KDB, which are activated in parallel for this purpose tires and reflectors of muscle (Papadopoulos et al. 2000). Finally, according to a survey of Takarada et al. (1997) the force developed during concentric contraction to jump with initial acceleration downward (CMJ) is greater than in the jump (SJ).

The purpose of this study was to evaluate the relationship of mechanical properties between vertical squat jump (SJ) and the concentric isokinetic test (Isokinetic Shortening Cycle) in three angle isokinetic dynamometer, where involved the total of kinematic chain of lower extremities (H-K-A), to check the possibility of using deliberate training loads.

Material & methods

Participants

The sample consisted of 18 students of physical education and sport sciences department of Serres, from different years of study, with no history of neurological injuries or diseases, gave written consent to participate in this study. Approval for the project was obtained from the committee on human research at the Aristotle University of Thessaloniki. All procedures used in this study were in conformity with the Declaration of Helsinki.

Table 1:. Characteristics of the sample

n=18	Age	Height	Weight
	(M±sd)	(M±sd)	(M±sd)
	19,78±1,63	178±6	74,4±8,5

Isokinetic machine of lower limbs

For the realization of the Isokinetic – SSC (ISSC), i.e. the concentric contraction, used an isokinetic construction, which is located in the Sports biomechanics Lab. Its function is based on the hydraulic pressure. It uses an electric motor 15PS, an oil tank 200lit. and a piston which is linked to the platform. The force plate fixated on this platform via two sliders, i.e. pressure regulator, which refers to the range of resistance that will reach and supply regulator, which regulates the speed of the platform (the piston speed) are the basic functions of ISSC. The complete hydraulic system is shown in figure 1.

Fig 1 : Multijoint Isokinetic Dynamometer

1. Seat, 2. Bolt 3. Force plate, 4. Velocity control, 5. Resistance control, 6. Electric engine

Kinematic Analysis

A method of two-dimensional video analysis used, for kinematic analysis of vertical jump, through kinematic analysis system APAS (Ariel Performance Analysis System). For the recording of motion of vertical

jump used a video camera type Panasonic AG 188, NTCS 60ft/sec, provided by the logging feature of motion with sampling frequency 60 Hz. automatically had the Video camera custom shutter speed between 1/60, 1/250, 1/500, depending on the brightness of the object. The Video camera was placed on a stable tripod, so as not to be subjected to vibration during capture and the optical axis was perpendicular to the drive shaft of the investigational and at a height of 10 m above ground level. For the determination of the joints and the members of the body were mounted reflectors (Lohmann et al., 1988) at the following locations: (a) the 5th metatarsal tubercle, b) out malleolus, c) outside (dent) of the knee, d) greater trochanter, and e) shoulder.

Reflectors were placed on the left side of the body of each participant and on the skin (naked surface) to minimize their movement because of the movement of clothes when performing jumps. On the classification of the area used the gradient box with dimensions 180x180cm, to meet the dimensions of space where held the movement (Ladin, 1995) Originally shot the cube gradient and then pulled away to take the vertical jump (DJ) and measurement in ISSC while the Video camera remained stable (not moved from position, did not suffer shocks and not attempted to enlarge (zoom), (Winters, 1990). Each motion capture looked at a list of the code and the number of vertical jump. For the digitization of selected points on the body, ought in principle to transfer the video file (.avi) in system analysis of APAS. Capture (capture) of motion of jumping was a period just before (10 images) takeoff from each time a different height of drop, the total support phase and a period shortly after the end of the support phase (10 images). Before starting the process of digitizing, registered the number of checkpoints, their coordinates and their measurement units (cm). The digitization of checkpoints and fixed point was in turn entered into the evaluation software of motion (APAS).

Dynamometer

For the measurement of ground reaction forces used a force plate KISTLER (9281CA). For the measurements of ISSC, the same forceplate was placed in a rigid metal frame, which was positioned at an angle of 75th, with the help of a metal shaft. To convert the analog signal into a digital signal used an analog-digital conversion card (ARIEL 16 A/D Channels) and to record a PC. The recording of the forces involved as the vertical component of the applied force, and both horizontal (x and y) to make possible the control of possible loss forces in specific areas. The sampling frequency was set at 1000Hz. might have for some time and through the forceplate recorded the course of reaction force of the ground in relation to time (manual Kistler).

From the graph of the change of power in relation to time, could then be calculated by integration of the relative area, speed, distance, and work and CC power at specific intervals Evaluated the vertical reaction force (Fz) of soil and then followed the process over time. Used specially adapted software program (Bioware for Windows, Kistler) to evaluate the relative force-time curve, push, time, maximum power, average power, maximum work, media work and the height of jumping (Papadopoulos et al., 2005).

Test protocol- Participants performed the following tests (Papadopoulos 2005) in forceplate (9281CA Kistler) with the use of kinematic analysis (APAS) and EMG (motion control co.): a) maximum vertical jumping (SJ) and b) three attempts in ISSC (speed of the platform: 0.74 m/sec). The duration of the concentric contraction is shown in table 2.

Table 2: Linear velocity and duration of concentric contraction in SJ and ISSC

Concentric phase	Velocity	time
ISC	0,74 m/sec	189 msec
SJ	2,21 m/sec	289 msec

Procedure

During the vertical jump (SJ) hands of the participants was motionless. This position of the hands was chosen in order to avoid the involvement of arms during jump (Bobbert & Van Ingen Schenau 1988; Van Soest et al., 1985) and to exclude the possibility of transferring momentum from swinging of the arms. During the course of conducting measurements each participant wore athletic pants (shorts) and track sneakers. To have a heightened neuromuscular preparation as well as a minimizing of the probability of injury, was warming up (10 min) and stretching exercises of the lower limbs (5 min). The tests executed in the following order: d) Maximum (3) vertical jumps (SJ), and b) Maximum (3) efforts in IKB.

Variables

Kinematic variables	Symbol	Unit of measurement
Acceleration displacement ob body $\ddot{\eta}$ ΠΔ	SKBΣ	cm
Angular displacement ΠKA	$\Delta\phi\Pi K$	o
Angular displacement ΑΓ	$\Delta\phi\Gamma$	o
Angular displacement ΑΙ	$\Delta\phi I$	o
Angular velocity ΠKA	$\Delta\phi\Pi K$	o/sec
Angular velocity ΑΓ	$\Delta\phi\Gamma$	o/sec
Angular velocity ΑΙ	$\Delta\phi I$	o/sec

Table 3: Kinematic variables

Dynamic variables	Symbol	Unit of measurement
Jump height	Hmax	cm
Take off velocity	V _{απ}	m·sec ⁻¹
Support time	τ _{σηρ}	sec
Maximal vertical force	Fz-max	N
Time of maximal force	tFz-max	N
Relative force	Fz-max/ΣB	index
Index of rate of force development (rfd)	ΔF/Δt	index
Time of rfd	tΔF/Δt	index
Power mean	PMO	Watt
Maximal power	Pmax	Watt
Work mean	WMO	Nm
Maximal work	W _{συγκ} -max	Nm

Table 4: Dynamic variables

Statistical analysis

This research used the design with a team, which was examined in two different tests (SJ & IKB). The format of this survey characterized relational is a sort of descriptive research, with which we can conclude the existence of relationships between two or more variables. Performance is composed so pairs of values. The control of all Affairs, involving comparisons between tests conducted with the assistance of the statistical program SPSS 10.0 for Windows. The statistical analysis of the data was divided into two sections. To investigate the quantitative characteristics of the tests used the method of descriptive statistics, which calculated the average, standard deviation and standard error of average and follows the method of inductive statistical for calculating correlations between variables of individual tests. The correlations were made by using the Pearson correlation coefficient (r). The correlations between the variables were calculated at significance level $p \leq 0.05$.

Results

The results showed statistically important correlations between the ISC and the vertical squat jump (DJ) in kinematic, dynamic characteristics of the two movements ($p \leq 0.05$).

Kinematics characteristics

More concretely the maximal angular velocity of the FA (SJ) presented statistical important relation with the maximal angular velocity of KA ($r = 0,582$, $p = 0,014^*$) and the time of force in the maximal curve of ISC ($r = 0,503$, $p = 0,033^*$). The maximal angular velocity of KA (SJ) presented statistical important relation with the maximal angular velocity of the KA ($r = 0,500$, $p = 0,041^*$) and the time of force in the maximal curve of ISC ($r = 0,509$, $p = 0,031^*$). The maximal angular velocity of the HA (SJ) presented statistical important relation with the time of force in the maximal curve of ISC ($r = 0,557$, $p = 0,016^*$). Also, the lower place of CM (SJ) presented statistical important relation with the force in the first 100msec ($r = -0,563$, $p = 0,015^*$), the force in the maximal curve ($r = -0,548$, $p = 0,019^*$) and the maximal angular velocity of the FA of ISC ($r = -0,515$, $p = 0,034^*$).

Dynamic characteristics

With regard to dynamic characteristics, the maximal force (SJ) presented statistical important relation with the force in the first 100msec of ISC ($r = 0,483$, $p = 0,042^*$). The take-off velocity (SJ) presented statistical important relation with the mean EMG of GAS in ISC ($r = 0,521$, $p = 0,027^*$) and the mean of Work (SJ) presented statistical important relation with the index of RFD in the ISC ($r = 0,551$, $p = 0,018^*$).

Discussion

The cinematic and dynamic variables of vertical jump (SJ) showed strong correlations with Cinematic and dynamic variables of ISSC. The growing momentum in jumping is not simply the result of the action of muscles of the lower limbs, but also of the upward acceleration of all joints, as well as contributes to the acceleration of the CG body, depending on their mass and acceleration of MS (Miller 1990). The eccentric (eccentric) workout seems to increase muscle strength and muscle hypertrophy (Fleck et al. 1997). There are also recent data that the workout with concentric and eccentric resistances, larger cams loads, accomplishes specific customizations for stronger and faster muscle using isokinetic protocols (Raue et al. 2005). With a few exceptions (Westcott et al. 2001), the investigations relating to the determination of eccentric strength using isokinetic devices. These studies show better results for the eccentric versus concentric isokinetic strength. It is not

presently known application of these differences in dynamic exercises (jumping). If these values identify feasible relevant training loads to improve coaching adjustments and protect from injury (Hortobagyi et al. 1996; Hollander et al. 2007). The relationships observed in the isokinetic SSC and vertical jump (SJ) concerning both kinematics and dynamic characteristics of the movements. The increased power production capacity during the concentric muscle contraction allows a more efficient control of muscle movement. This means a possible protection to 'sensitive' mechanisms of neuromuscular system from fatigue due to high impact forces or repetitive smaller forces (Komi 1984). Besides, there are assumptions that the concentric muscle activation requires specific operational strategies of the nervous system (Hortobagyi et al. 1996). The causes of performance rendered on elastic behavior of muscles during and after eccentric contraction, where through the distension, change conditions in the muscles increasing the action of following concentric phase. The kinetic energy of the body falls (DJ) is converted to active deformation of their musculotendinous system and in the short term is saved. To the extent that follows through the concentric contraction takes place over a conversion into kinetic energy, which is equivalent to an increase of pushing power, developed during concentric contraction (Bührlé 1989). The need for improving performance in SSC leads in finding the ideal height of fall and the ideal support time to achieve maximum vertical jumps (DJ). So to determine the "ideal" height of fall, the sample performs vertical jumps, where the drop height ranges between 20-100 cm. The "ideal" drop height is this, which the sample will achieve the maximum vertical displacement of the CC (Katschajov et al. 1975).

Conclusion

Based on the results of correlation degree could the ordeal of ISSC be considered a worthwhile test (test) for measuring dynamic and courier-dynamic variables, an important application of seems to be present in the process of training.

References

- Blazevich A.J., Jenkins D.J. (1998). Predicting sprint running times from isokinetic and squat lift tests: A Regression Analysis *J Strength Cond. Research*, 12:2, 101–103.
- Bobbert, M.F. & Van Ingen Schenau (1988). Coordination in vertical jumping. *J of Biomechanics*, 21:3, 249-262.
- Bosco, C., Komi, P.V. (1979). Potentiation of mechanical behavior of the human skeletal muscle prestretching. *Acta Physiol. Scand.* 106: 467-472.
- Bosco, C., Komi, P.V., Locatelli, E. (1979). Physiologische Betrachtungen zum Tiefsprungtraining. *Leistungssport*, 6: 434-438.
- Bosco, C., Pittera, C. (1982). Zur Trainingswirkung neuentwickelten Sprungübungen auf die Explosivkraft. *Leistungssport*, 12: 36-39.
- Bosco, C., Viitasalo J.T., Komi, P.V., & Luthanen, P. (1982). Combine effect of elastic energy and myoelectrical potentiation during stretch-shortening cycle exercise. *Acta Physiologica Scandinavica*, 114, 557–565.
- Bührlé M. (1985). Dimensionen des Kraftverhaltens und ihre spezifischen Trainingsmethoden. In: Grundlehren des Maximal- und Schnellkrafttrainings. M. Bührlé
- Caiozzo V.J., Perrine J. J., Edgerton V.R. (1981) Training-induced alterations of the in vivo force-velocity relationship of human muscle. *J Appl Physiol* 51: 750-754.
- Chapman, D.W., Newton, M.J., Zainuddin, Z., Sacco, P., Nosaka, K. (2007) Work and Peak Torque during Eccentric Exercise Do Not Predict Changes in Markers of Muscle Damage.
- Chen, T.C., Nosaka, K., Sacco, P. (2007). Intensity of eccentric exercise, shift of optimum angle, and the magnitude of repeated-bout effect. *Journal of Applied Physiology*, 102, 992-999.
- Clutch, D., Wilton, M., McGown, C., Bryce, G. (1983). The effect of depth jumps and eight training on leg strength and vertical jump. *Res Q exerc Sport.* 54: 5-10.
- Dowson M.N., Nevill M.E., Lakomy H.K., Nevill A.M., Hazeldine R.J. (1998). Modeling the relationship between isokinetic muscle strength and sprint running performance. *J Sports Sci* 16:3, 257-65.
- Duclay, J., Martin, A., Robbe, A. & Pousson, M. Spinal reflex plasticity during maximal dynamic contractions after eccentric training. (2008). *Med Sci Sports Exerc* 40,722-734, doi10.1249/MSS.0b013e31816184dc
- Enoka, R.M. (1996). Eccentric contractions require unique activation strategies by the nervous system. *J. Appl. Physiol*, 81, 2339-2346.
- García-López, J., Peleteiro, J., Rodríguez-Marroyo, J.A., Morante, J.C., Herrero, J.A., & Villa, J.G. (2005). The validation of a new method that measures contact and flight times during vertical jump. *International Journal of Sports Medicine*, 26 (4), 294-302.
- Gissis I. (2003). Exzentrisch erzwungene maximale Kraftwerterhöhungen als reaktiver Impulsgeinn interpretiert. *Sportwissenschaft*, 1:62-75.
- Hortobagyi, T., Hill, J.P., Houmard, J.A., Fraser, D.D., Lampert, J., & Israel, R.G. (1996). Adaptive responses to muscle lengthening and shortening in humans. *Journal of Applied Physiology*, 80(3), 765-772.
- Katschajov, S.V., Gomberadse, K.G., Revson, A.S. (1975). Determinazione dell intensita di carico ottimale nella costruzione della capecita di sprinta degli atleti (juniores). *Atletica leggera*, traduzione da. *Die Lehre der Leichtathletik*, 44.

- Komi P.V. (1984) Biomechanics and neuromuscular performance. *Med Sci Sports Exerc.*;16(1):26-8.
- Komi, P.V., & Bosco, C. (1978). Utilization of stored elastic energy in leg extensor muscles by men and women. *Medicine and Science in Sports and Exercise*, 10, 262-265.
- Korff, T., Horne, S.L., Cullen, S.J., & Blazevich, A.J. (2009). Development of lower limb stiffness and its contribution to maximum vertical jumping power during adolescence. *Journal of Experimental Biology*, 212(22), 3737-42.
- Kubo K., Kawakami Y., Fukunaga T. (1999) Influence of elastic properties of tendon structures on jump performance in humans *J Appl Physiol*, 87:2090-2096.
- Kues, J.M & Mayhew, T.P. (1996). Concentric and eccentric force- velocity relationships during electrically induced submaximal contractions. *Physiotherapy Research International*, 1(3), 195-203.
- Lands L.C, Hornby L., Desrochers G., Iler T., Heigenhauser G.J. (1994) A simple isokinetic cycle for measurement of leg muscle function. *J of Appl. Physiology*, 77:5, 2506-2510.
- Lavender AP , K Nosaka (2006). Changes in fluctuation of isometric force following eccentric and concentric exercise of the elbow flexors. *European Journal of Applied Physiology* ,96:235-240.
- Lazaridis, S., Bassa, E., Patikas, D., Giakas, G., Gollhofer, A., & Kotzamanidis, C. (2010). Neuromuscular differences between prepubescent boys and adult men during drop jump. *European Journal Applied Physiology*, 110(1), 67-74.
- Li R.C., Wu Y., Maffulli N., Chan J.L. (1999). Eccentric and concentric isokinetic knee flexion and extension: a reliability study using the Cybex 6000 dynamometer *Br. J of Sports Med.*, 33:2, 113-116.
- Liu, Y., Shih, S.M., Tian, S.L., Zhong, Y.J., & Li, L. (2009). Lower extremity joint torque predicted by using artificial neural network during vertical jump. *Journal of Biomechanics*, 42(7), 906-11.
- Lohmann G.T., Roche F.A., Martorell R. (1988). Anthropometric Standardization Reference Manual. Human Kinetics Books. Champaign.
- Martin, D., Carl, K., Lehnertz, K. (1993). Handbuch Trainingslehre. Hofmann. Schorndorf. Ελληνική μετάφραση. Εγχειρίδιο Προπονητικής. Εκδ. Σάλτος (1995) s. 158-159, 123-124.
- Miller I.D. (1990). Ground reaction forces in distance running. In: Cavanagh R.P. (Ed): *Biomechanics of distance running*. s. 203-224.
- Norrbbrand, L., Fluckey, J., Pozzo, M., Tesce, P.A. (2008). Resistance training using eccentric overload induces early adaptations in skeletal muscle size. *Eur J Physiol*, 102, 271-281.
- Paasuke, M., Ereline, J., Gapeyeva H. (2001). Knee extension strength and vertical jumping performance in nordic combined athletes. *J Sports Med Phys Fitness*. 41:3, 354-61.
- Papadopoulos C. et al., (2000). Diagnose und Auswertung der motorischen Fähigkeiten Kraft und Schnelligkeit b. jungen Schwimmern. *Leistungssport* 4:14-17.
- Papadopoulos C., Smirnioti A., Gallos G., Tsintzos P., Gantiraga E., Komsis G., Gissis I. (2005) Growth of a measurement system for the evaluation of force and speed in sports, *Sports Organisations*, 3 (1-2)35-42.
- Pereira, G., de Freitas P.B., Rodacki, A., Ugrinowitsch, C., Fowler, N., & Kokubun, E. (2009). Evaluation of an innovative critical power model in intermittent vertical jump. *International Journal of Sports Medicine*, 30(11), 802-7.
- Raue U, Terpstra B, Williamson DL, Gallagher PM, Trappe SW. (2005) Effects of short-term concentric vs. eccentric resistance training on single muscle fiber MHC distribution in humans. *Int J Sports Med*. Jun;26(5):339-43
- Schmidtbleicher, D., & Gollhofer, A. (1982). Neuromuskuläre Untersuchungen zur Bestimmung individueller Belastungsgrößen fuer ein Tiefsprungtraining. *Leistungssport*, 12, 298-307.
- Schmidtbleicher, D., Gollhofer, A. (1982). Neuromuskuläre Untersuchungen zur Bestimmung individueller Belastungsgrößen für ein Tiefsprungtraining. *Leistungssport*, 12:298-307.
- Steben, R.E., Steben, A.H. (1981). The validity of the stretch shortening cycle in selected jumping events. *Journal of Sports Medicine*, 21:28-37.
- Tsatalas, T., Lazaridis, S., Zaggelidis, G., & Kotzamanidis, C. (2010). The effects of a stretch-shortening cycle fatigue protocol on knee kinematics during running in untrained children. *Journal of Physical Education and Sport (JPES)*, 27(2), 39-43.
- Van Soest A.J., Schwab, A.L., Bobbert, M.F., van Ingen Schenau G.J. (1993). The influence of the bi-articularity of the gastrocnemius muscle on vertical jumping achievement. *J of Biomechanics*, 26:1-8.
- Walshe, A.D, Wilson, G.J, Ettema, J.C. (1998). Stretch-shorten cycle compared with isometric preload: contributions to enhanced muscular performance. *J. Appl. Physiol*. 84:1, 97-106.
- Westcott WL, Winett RA, Anderson ES, Wojcik JR, Loud RL, Cleggett E, Glover S. (2001) Effects of regular and slow speed resistance training on muscle strength. *J Sports Med Phys Fitness*. Jun;41(2):154-8.
- Wilson, G.J, Walshe, A.D, Fisher M.R. (1997). The development of an isokinetic squat device: reliability and relationship to functional performance *Euro J of Applied Phys. & Occup Physiology*, 75:5, 455-461.
- Winters J.M. (1990) Hill-based muscle models: a systems engineering perspective. In: Winters J.M. & Woo S.L. (Ed.) *Multiple Muscle Systems: Biomechanics and Movement Organization*. New York: Springer, 69-93