The usefulness of jumping technology on program designing for the personal training and strength and conditioning coach

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Abstract

Nowadays, practical technological tools for assessing jumping performance are broadly available. Jump test is timesaving and of excellent reliability and validity. The author uses the ChronoJump contact mat; the ChronoJump contact mat is successful and independently tested for reliability and validity. [1] Test results can be used to develop an effective training program for clients and athletes.

Keywords: Jump, ChronoJump, Testing.

1. Jump Testing

The efficiency of the lower body, in particular jumping abilities, is proven to be an excellent measurement for predicting the performance of a variety of sports tasks. [2-7] Vertical jump performance is related to one's body weight, following Newton's Law of motion; the more substantial the object, the higher the inertia, and the more force needed to bring the object (human body) in action. Some authors prefer to include countermovement jump peak force relative to body weight; this is successfully tested as a valid predictor of sprint performance. [8] Jump height and peak-power output results can be compared to other athletes'; this can be done by comparing against results founded in research papers, as in Table 1. When working with a team, comparisons can be made between players of the group. Hence, that some playing positions could develop different levels of jumping height and peak-power outputs because of the specific positional demands, correcting may not always lead to increased field performance. When working with personal training client's comparisons can be made between the gym members, a wall where the jump height of the clients can be compared can be both motivative as fun for the clients.

	Soccer	Tennis	Endurance	Power
SJ (cm)	38.28 ± 3.30#	36.61 ± 3.87#	30.47 ± 3.06	44.77 ± 5.56*
CMJ (cm)	40.95 ± 2.95#	39.14 ± 4.27#	32.37 ± 3.80	48.31 ± 6.25*
DJ (cm)	39.07 ± 3.70#	39.39 ± 3.85#	29.33 ± 4.64	43.52 ± 5.44*

* Values greater than all other groups ($P < 0.05$).
# Values greater than endurance group ($P < 0.05$).

Figure 1: CMJ height of athletes; Copied from Kobal et al. [17]

Other measurements that can be extracted from a jump test next to jump height and peak power output is the efficiency of the stretch-shortening cycle (SSC). This can be obtained from the difference in squat-jump (S.J.) and countermovement jump (CMJ) height [11] or with the reactive-strength index (RJI). [9-10] The SSC consist of an eccentric pre-stretch phase, isometric or transition phase, into an explosive concentric phase; referred to as the reversible action of the muscle. [12] The mechanical model by which the SSC works is by storing elastic energy that can be released during the concentric muscle action, similar to a spring. As an example, during initial foot contact with the ground elastic energy is stored and released during the push-off phase. [13] The second proposed mechanics is the neurophysiological model, it has been suggested that the muscle spindles initiate a

reflex that is responsible for a potentiated effect – more motor units or recruited or increased rate of muscle firing. [15,16] The SSC can be further divided in the fast- and slow SSC – fast SSC is used when ground contact times are <250ms, and slow SSC when ground contact times exceed 250ms. The SSC is broadly researched, further information can be found in Turner et al.; The Stretch-Shortening Cycle: Proposed Mechanisms and Methods for Enhancement. [14]

Jumping test that the author suggests performing in a gym environment and data that can be collected with the ChronoJump contact mat and software from the test are presented in Table 2. Note that more test can be done with the ChronoJump contact mat.

Jump test:	Data collected from the test(s):
Countermovement jump (CMJ)	Height, flight time, initial speed & power
Squat jump (S.J.)	Height, flight time, initial speed & power
Reactive jump (R.J.)	Height, contact time, power, stiffness, initial speed & Fast SSC efficiency (from analysing and comparing data)
CMJ to S.J. comprising	Index % (difference between jumps) & Slow SSC efficiency (indirect by index % results)

Figure 2: Jump test and data collected from the test

2. Improving jump test scores with plyometric training

One of the training laws we always have to keep in mind is; SAID – specific adaptations to imposed demands. So then, the best option to improve jumping performance is by regularly train to jump with plyometric training (P.T.). P.T. is an explosive bodyweight resistance exercise that effectively trains the SSC. [19] P.T. exercises can be performed; single-leg, double-leg, vertical or horizontal, etcetera. [20-22] PT has a positive effect on running economy even without improving $VO2_{max}$ and in a short period of <10 weeks [24-26], it improves the vertical jump [27], 10-meter sprint time and agility performance [28], and some exercises reduce injury risk as the single-leg sagittal plane hurdle hops [29]. In terms of P.T. volume, there has been advised volumes of 80 ground contact times [30] up to 400 [31] ground contact times for trained adults. A study by William P. Ebben and colleagues [32] concluded that there was not a significant difference between low- to moderate and high volume periodized plyometric training. Therefore, the author suggests optimal loads are +/-120 contact times what are often performed with intermediate athletes [30]. Note that as already discussed adaptation is specific, for improving horizontal force production, training horizontal P.T. exercises are more effective than vertical P.T. exercises, as perceived during the swimming start. [23]

3. Using P.T. as a potentiation exercise for short term improvements of (jump) performance

Short-term increases in power output and rate-of-force development (RFD) following a bout of resistance exercise believed to be the result of post-activation potentiation (PAP) response. Traditionally PAP-response is investigated after a session of heavy resistance training exercise, which due it is low-velocity, does not appear to be the most suitable choice in all situations. An introduction to complex training provided as often jump- and plyometric exercises are performed with complex training. The purpose of this research is to review if there is a comparable PAP response following a bout of plyometric training exercise measured during CMJ performance on the ChronoJump contact mat.

3.1 Post-activation Potentiation (PAP) mechanism

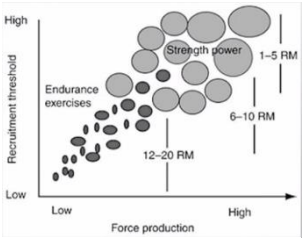

Figure 3: Hellemans size principle

Defined initially by Robbins [52], PAP is a phenomenon by which the force exerted by a muscle increased due to its previous contraction. A brief duration of non-fatiguing muscular contractions might enhance muscular performance. [52] There are several proposed mechanisms behind the PAP-response; one is the recruitment of high-threshold motor units. [54] Motor unit recruitment provides the physiological basis for force production at any movement velocity. [57] Typically motor unit activation is

directly connected to its size as defined in Henneman's theory of motor unit recruitment (figure 1.). [55-56] Theorised that due to the preload exercise, high-threshold motor units recruit first–usually would not be recruited. The second proposed mechanism is the phosphorylation of myosin regulatory light chains. [54] Due to the preload exercises, the sarcoplasmic reticulum (S.R.) releases calcium ions (CA+) that binds to troponin. The binding of CA+ to troponin causes a shift in another protein molecule, tropomyosin, that runs along the length of the actin filament in the groove of the double helix. [58]

3.2 Influences on PAP-response

Several factors influence the PAP-response per individual; the elements are the following: biomechanical similarity between the preload and power exercises, [33-38] the athletes training experience and level of strength, [39-44] the intensity of the preload exercise, [45,46] and rest period between preload and power exercise. [47-50] Duthie et al. [40] observed significant differences in PAP-response in female hockey players. Relative, more influential players potentiate greater compared to their weaker counterparts. Nabil et al. [51], concluded significant variations in PAP-response per individual at 3-7 minutes following preload exercises. Recommended that Strength & Conditioning Coach test his athletes to find their optimal rest interval within preload and sport tasks or explosive exercises.

3.3 Complex Training

Currently, there is a wealth of information on complex training (C.T.) and the performance effect. [59] Complex training is performed by using a heavy preload exercise followed by an explosive biomechanical similar exercise. Depending on the particular athlete, a rest interval of 3-7 minutes is optimal. [40] During rest intervals, mobility and stability drills for the unaffected limbs can be implemented - addressing dysfunctional movement patterns. [60-61] Matthew et al. [58] stress that when implementing C.T. to increase speed and power, that the athlete should not get fatigued.

3.4 Practical

The PAP-response is highly beneficial to pre-competition and pre-training. Performing heavy resistance exercise pre-competition is not recommended due to the low- movement velocity or when the training session is performed on the field. Sharma et al. [61] tested collegiate soccer players PAP-response by CMJ height after a bout of 40 squat-jumps (S.J.) and compared it to a more traditional preload exercise, the barbell back squat at 90% of 1RM. The auteurs concluded that plyometrics appears to be a more reliable alternative than heavy resistance exercises. Of all the research, the author recommends plyometric exercise in the warm-up or early in the training session, and if necessary, use complex training to sustain the PAP-response.

3.5 Additional: Personal Research

Out of curiosity, the author has put the research into the test, implementing both of the practical suggestions just mentioned in a real-life scenario where optimal rest intervals could not always be measured. The 7 athletes examined for this research are from a diversity of backgrounds, including amateur athletes, men, and women, all from diverse age categories.

CMJ heights measured with a ChronoJump contact mat, again, the ChronoJump contact mat is successful and independently tested for validity and reliability. [42]

The first measurement obtained directly after a traditional warm-up, including the myofascial release with a foam roller, and the activation exercises are performed with a kettlebell (squat and deadlift), the second measurement after a bout of 100 pogo jumps and 20 S.J.'s.

Results: Significant difference is observed after preloading sets with plyometric exercises; the athletes significantly jumped higher following the plyometric exercises. The average CMJ height increased by 8.85%. These findings demonstrate that performing a series of plyometric exercises either in the warming-up or early on in the training session provides a short-term improvement in CMJ, and thus, in a variety of sports tasks. [2-7]

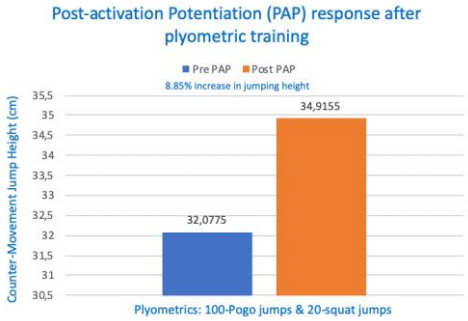

Figure 4: Personal Research Findings

4. Preparing the athlete safely for jump- and plyometric training

Before starting an intervention that includes jump- and plyometric exercises, a foundation of excellent landing mechanics must be presented. A non-lab-based test that can be performed without expensive equipment is the landing error scoring system-real time (LESS-RT). The test is positively tested for reliability [62] and consist of a jump of a box to a vertical jump. Jump landing characteristics are scored, where excellent is scored 0 and weak either with a 1 or 2, for the end score, the closer to 0, the superior. There are other jump tests that are timesaving and from superior reliability. [63,64] One of those tests is the single-leg triple hop test for a distance that is used as an assessment of interlimb differences (asymmetry.) [63] It is suggested that an interlimb difference more significant than 15% increases injury risk. [65] Researchers observed adverse effects on jumping performance indicated by interlimb variations of only 6-8%. [66] Further, researched mentioned no negatives effect on linear speed and change-of-direction (COD) capabilities with interlimb differences of 11.4%. [67] Other hypothetically purpose an interlimb difference threshold of <10% based on inclusiveness of current research. To summarise, performing the LESS-RT test and the single-leg triple hop test for distance as an assessment of landing mechanics and interlimb differences can help to establish an effective intervention before starting an intensive jump- and plyometric training plan. An example of an excellent exercise to develop landing mechanics is presented below.

Figure 5A Landing mechanics drill

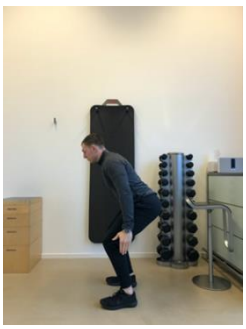

Figure 6B Landing mechanics drill

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References

[1] Basilio Pueo, Jose M. Jimenez-Olmedo, Patrycja Lipińska, Krzysztof Buśko, Alfonso Penichet-Tomas, Concurrent validity and reliability of proprietary and open-source jump mat systems for the assessment of vertical jumps in sport sciences, Acta of Bioengineering and Biomechanics Original paper Vol. 20, No. 3, 2018.

[2] Nuzzo, JL, Anning, JH, and Scharfenberg, JM. The reliability of three devices used for measuring vertical jump height. J Strength Cond Res 25: 2580–2590, 2011.

[3] Docherty, D, Robbins, D, and Hodgson, M. (2004). Complex training revisited: A review of its current status as a viable training approach. Strength Cond J, 27(4), pp.50-55.

[4] Markstrom, JL and Olsson, CJ. Countermovement jump peak force relative to body weight and jump height as predictors for sprint running performances: (In)homogeneity of track and field athletes? J Strength Cond Res 27(4): 944–953, 2013 [

[5] Irineu Loturco, Ciro Winckle, Ronaldo Koba, Cesar C. Cal Abad, Katia Kitamura, Amaury W. Veríssimo › Lucas A. Pereira and Fábio Y. Nakamura, Performance changes and relationship between vertical jump measures and actual sprint performance in elite sprinters with visual impairment throughout a Parapan American games training season, Front. Physiol. 6:323. doi:10.3389/fphys.2015.00323.

[6] Abbas Asadi, Relationship Between Jumping Ability, Agility and Sprint Performance of Elite Young Basketball Players: A Field-Test Approach, Revista Brasileira de Cineantropometria e Desempenho Humano · March 2016.

[7] Haci Murat Sahin, Relationships between acceleration, agility, and jumping ability in female volleyball players, European Journal of Experimental Biology, 2014, 4(1):303-308.

[8] Jonas L. Markstro¨ M And Carl-Johan Olsson, Counter-movement Jump Peak Force Relative To Body Weight And Jump Height As Predictors For Sprint Running Performances: (In)Homogeneity Of Track And Field Athletes? Journal of Strength and Conditioning Research, Volume 27, Number 4, April 2013.

[9] Comyes TM, Harrison AJ, Hennessey L, Jensen RL. Identifying the optimal resistive load for complex training in male rugby players. Sports Biomech 2007;6 (6): 59-70.

[10] Ebben WP, Petushek EJ. Using reactive strength index modified to evaluate plyometric performance. J Strength Con Res 2010;24 (8): 1983-7.

[11] Bobbert MF, Gerritsen KGM, Litjens MCA, and Van Soest A.J. Why is countermovement jump height greater than

squat jump height? Med Sci Sports Exerc 28: 1402–1412, 1996.
[12] Zatsiorsky VM and Kraemer WJ. Science and Practice of Strength Training. Champaign, IL: Human Kinetics, 2006. pp. 33–39.
[13] Hobara H, Kimura K, Omuro K, Gomi K. Muraoka T, Iso S, and Kanosue K. Determinants of difference in leg stiffness between endurance- and power-trained athletes. J Biomech 41: 506–514, 2008.
[14] Anthony N. Turner, MSc, CSCS and Ian Jeffreys, The Stretch-Shortening Cycle: Proposed Mechanisms and Methods for Enhancement, Strength and Conditioning Journal, Volume 32 Number 4 | August 2010.
[15] Bosco C, Komi P.V., and Ito A. Pre-stretch potentiation of human skeletal muscle during ballistiv movement. Acta Physiol Scand 111: 135–140, 1981.
[16] Butler RJ, Crowell HP, and Davis IM. Lower extremity stiffness: Implications for performance and injury. Clin Biomech 18: 511–517, 2003.
[17] R. Kobal, F.Y. Nakamura, K. Kitamura, C.C. Cal Abdad, L.A. Pereira, L. Loturco, Vertical and depth jumping performance in elite athletes from different sports specialties, Science and Sports, 2017.
[18] Schmidtbleicher D. Training for power events. In: Strength and Power in Sport. Komi P.V., ed. Oxford, United Kingdom: Blackwell Science, 1992. pp. 169–179.
[19] Vaczi M, Racz L, Hortobagyi T, and Tihanyi J. Dynamic contractility and efficiency impairments in stretch-shortening cycle are stretch-load-dependent after training-induced muscle damage. J Strength Cond Res 27: 2171–2179, 2013.
[20] Fowler NE, Trzaskoma Z, Wit A, Iskra L, and Lees A. The effectiveness of a pendulum swing for the development of leg strength and countermovement jump performance. J Sports Sci 13: 101–108, 1995.
[21] Saez-Saez de Villarreal E, Requena B, and Newton RU. Does plyometric training improve strength performance? A meta-analysis. J Sci Med Sport 13: 513–522, 2010.
[22] Wisloff U, Castagna C, Helgerud J, Jones R, and Hoff J. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. Br J Sports Med 38: 285–288, 2004.
[23] Rebutini VZ, Pereira G, Bohrer RC, Ugrinowitsch C, and Rodacki AL. Plyometric long jump training with progressive loading improves kinetic and kinematic swimming start parameters. J Strength Cond Res 2014 February 12. [Epub Ahead of Print.]
[24] Spurs RW, Murphy AJ, and Watsford ML. The effect of plyometric training on distance running performance. Eur J Appl Physiol 89: 1–7, 2003.
[25] Saunders PU, Telford RD, Pyne DB, Peltola EM, Cunningham RB, Gore CJ, and Hawley JA. Short-term plyometric training improves running economy in highly trained middle and long-distance runners. J Strength Cond Res 20: 947–954, 2006.
[26] Turner AM, Owings M, and Schwane JA. Improvement in running economy after 6 weeks of plyometric training. J Strength Cond Res 17: 60–67, 2003.
[27] Khlifa R, Aouadi R, Hermassi S, Chelly MS, Jlid MC, Hbacha H, and Castagna C. Effects of a plyometric training program with and without an added load on jumping ability in basketball players. J Strength Cond Res 24: 2955–2961, 2010.
[28] Meylan C and Malatesta D. Effects of in-season plyometric training within soccer practise on explosive actions of young players. J Strength Cond Res 23: 2605– 2613, 2009.
[29] Struminger AH, Lewek MD, Goto S, Hibberd E, and Blackburn JT. Comparison of gluteal and hamstring activation during five commonly used plyometric exercises. Clin Biomech(Bristol,Avon) 28:783–789,2013.
[30] Potach, D.H., & Chu, D.A. (2008). Plyometric Training. In: Beachle, T.R, & Earle, R.W, editors. Essentials of Strength Training and Conditioning. (pp 413-427). Champaign: Human Kinetics.
[31] Chu, D.A. & Myer, G. (2013). Volume and recovery guidelines for young athletes. In: Plyometrics. (pp 39-66). Champaign: Human Kinetics.
[32] William P. Ebben and colleagues, the effect of plyometric training volume on jumping performance, International Conference of Biomechanics in Sports, July 2014, DOI: 10.13140/2.1.1551.4245.
[33] Crewther BT, Kilduff LP, Cook CJ, Middleton MK, Bunce PJ, and Yang GZ. The acute potentiating effects of back squats on athlete performance. J Strength Cond Res 25: 3319–3325, 2011.
[34] Ebben WP. Complex training: A brief review. J Sports Sci Med 1: 42–46, 2002.
[35] Ebben WP, Jensen RL, and Blackard DO. Electromyographic and kinetic analysis of complex training variables. J Strength Cond Res 14: 451–456, 2000.
[36] Ebben WP and Watts PB. A review of combined weight training and plyometric training modes: Complex training. Strength Cond J 20: 18–27, 1998.
[37] Guggenheimer JD, Dickin DC, Reyes GF, and Dolny DG. The effects of specific preconditioning activities on acute sprint performance. J Strength Cond Res 23: 1135–1139, 2009.
[38] Chiu LZ, Fry AC, Weiss LW, Schilling BK, Brown LE, and Smith SL. Post activation potentiation response in athletic and recreationally trained individuals. J Strength Cond Res 17: 671–677, 2003.
[39] Duthie GM, Young WB, and Aitken DA. The acute effects of heavy loads on jump squat performance: An evaluation of the complex and contrast methods of power development. J Strength Cond Res 16: 530–538, 2002.
[40] Ruben RM, Molinari MA, Bibbee CA, Childress MA, Harman MS, Reed KP, and Haff GG. The acute effects of an ascending squat protocol on performance during horizontal plyometric jumps. J Strength Cond Res 24: 358–369, 2010.
[41] Seitz LB, de Villarreal ES, and Haff GG. The temporal profile of post-activation potentiation is related to strength level. J Strength Cond Res 28: 706–715, 2014.
[42] Suchomel TJ, Sato K, DeWeese BH, Ebben WP, and Stone MH. Potentiation following ballistic and non-ballistic complexes: The effect of strength level. J Strength Cond Res 30: 1825–1833, 2016.

[43] Sygulla KS and Fountaine CJ. Acute postactivation potentiation in NCAA Division II female athletes. Int J Exerc Sci 7: 212– 219, 2014.

[44] Wilson JM, Duncan NM, Marin PJ, Brown LE, Loenneke JP, Wilson SM, Jo E, Lowery RP, and Ugrinowitsch C. Meta-analysis of post-activation potentiation and power: Effects of conditioning activity, volume, gender, rest periods, and training status. J Strength Cond Res 27: 854–859, 2013.

[45] Yetter M and Moir GL. The acute effects of heavy back and front squats on speed during forty-meter sprint trials. J Strength Cond Res 22: 159–165, 2008.

[46] Crewther BT, Kilduff LP, Cook CJ, Middleton MK, Bunce PJ, and Yang GZ. The acute potentiating effects of back squats on athlete performance. J Strength Cond Res 25: 3319–3325, 2011.

[47] Kilduff LP, Bevan HR, Kingsley MI, Owen NJ, Bennett MA, Bunce PJ, Hore AM, Maw JR, and Cunningham DJ. Post activation potentiation in professional rugby players: Optimal recovery. J Strength Cond Res21: 1134–1138, 2007.

[48] Nibali ML, ChapmanDW, Robergs RA, and Drinkwater EJ. Considerations for determining the time course of post-activation potentiation. Appl Physiol Nutr Metab 40: 1163–1170, 2015.

[49] Turner AP, Bellhouse S, Kilduff LP, and Russell M. post-activation potentiation of sprint acceleration performance using plyometric exercise. J Strength Cond Res 29: 343–350, 2015.

[50] Nibali ML, ChapmanDW, Robergs RA, and Drinkwater EJ. Considerations for determining the time course of post-activation potentiation. Appl Physiol Nutr Metab 40: 1163–1170, 2015.

[51] Robbins D.W. Post activation potentiation and its practical applicability: a brief review. J Strength Cond Res. 2005; 19: 453-458.

[52] Stone MH, Sands W, Pierce K, et al. Power and power potentiation among weightlifters: a preliminary study. Int J Sports Physiol Perform. 2008; 3: 55-67.

[53] Tillin NA and Bishop D. Factors modulating post-activation potentiation and its effect on the performance of subsequent explosive activities. Sports Med 39: 147–166, 2009.

[54] Henneman E. Relation between the size of neurons and their susceptibility to discharge. Science 126: 1345–1347, 1957.

[55] Henneman E. The size-principle: A deterministic output emerges from a set of probabilistic connections. J Exp Biol 115: 105–112, 1985.

[56] William J. Kraemer and David P. Looney, Underlying Mechanisms and Physiology of Muscular Power, National Strength and Conditioning Association, volume 34 | number 6 | December 2012.

[57] Billeter, R, and Hoppeler, H, Muscular basis of strength. In the encyclopaedia of sports medicine strength and power in sports. 2nd ed. Komi, P.V., ed, OxfordL Blackwell Science, 50-72, 2003.

[58] Matthew S. J. Tredrea, Applied Complex Training: An Updated Review And Practical Applications, J. Aust. Strength Cond. 25(3) 71-85. 2017 © ASCA.

[59] Cook G, BurtonL, and Kiesel. Movement. Functional Movement Systems: Screening, Assessment and Corrective Strategies. Santa Cruz, CA. On Target Publications, 2010.

[60] Julian J. H. Lim, and Christopher I. Barley, Complex Training for Power Development: Practical Applications for Program Design, Strength and Conditioning Journal, Volume 38 | Number 6 | December 2016.

[61] Sourabh Kumar Sharma, Shahid Raza, Jamal Ali Moiz, Shalini Verma, IrshadHusain Naqvi, Shahnawaz Anwer, and Ahmad H.Alghadir, Postactivation Potentiation Following Acute Bouts of Plyometric versus Heavy-Resistance Exercise in Collegiate Soccer Players, Bio Med Research International, Volume 2018, Article ID 3719039.

[62] Darin A. Padua, Michelle C. Boling, Lindsay J. DiStefano, James A. Onate, Anthony I. Beutler, and Stephen W. Marshall, Reliability of the Landing Error Scoring System-Real Time, a Clinical Assessment Tool of Jump-Landing Biomechanics, Journal of Sport Rehabilitation, 2011, 20, 145-156.

[63] Mary Williams, AntonioSquillante, Dott, and Jay Dawes, The Single Leg Triple Hop for Distance Test, Strength and Conditioning Journal, Volume 39 | Number 3 | June 2017.

[64] Paul J. Read, Jon L. Oliver, Mark B.A. De Ste Croix, Gregory D. Myer, And Rhodri S. Lloyd, Reliability Of The Tuck Jump Injury Risk Screening Assessment In Elite Male Youth Soccer Players, Journal of Strength and Conditioning Research, Volume 30 | Number 6 | June 2016.

[65] Bishop C,Read P,Chavda S, and Turner A. Asymmetries of the lower limb: The calculation conundrum in strength training and conditioning. Strength Cond J 38: 27–32, 2016.

[66] Bailey C, Sato K, Alexander R, Chiang CY, and Stone MH. Isometric force production symmetry and jumping performance in collegiate athletes. J Trainology 2: 1–5, 2013.

[67] Dos'Santos T, Thomas C, Jones PA, and Comfort P. Asymmetries in single and triple hop are not detrimental to change of direction speed. J Trainology 6: 35–41, 2017.

[68] Chris Bishop and colleagues, Training Methods and Considerations for Practitioners to Reduce Interlimb Asymmetries, National Strength and Conditioning Association, volume 40 | number 2 | April 2018.