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Kinematics in Lateral Plyometric Jumping Exercise at Different Distances

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Abstract: *Jump-based exercises, such as plyometrics, are reported to be an effective method for the development and enhancement of physical qualities in the legs, for example power and reactive strength, for change of direction movements. The purpose of the study was to examine a unilateral jump over different distances, with the aim of quantifying the changes that occur to joint displacement at the hip, knee and ankle joints, as well as changes to ground contact time (GCT). Eight healthy participants took part in the study, each of whom had previous experience of sports, which included change of direction movements. Results of a repeated measures ANOVA revealed significant differences to GCT on the right leg ($P < 0.05$) but not on the left ($P > 0.05$) as jump distance increased. For joint displacement, significant differences were observed at the right ankle and right knee but not at any other joint. The results of the study confirm that this particular activity is not suited for training to improve change of direction speed (CODS) performance. Group means and the discussion can aid practitioners in an appropriate exercise selection for training programming.*

Keywords: *Plyometric, Reactive Strength, Stretch Shortening Cycle, Joint Displacement, Unilateral Jump*

Abbreviations: *GCT – Ground Contact Time, CODS – Change of Direction Speed, RFD, Rate of Force Development, ANOVA – Analysis of Variance*

1. Introduction

The performance of agility and change of direction (COD) movements have been identified as components which are essential to many different sports and are integral for successful performance within these sports [1,2]. Miller *et al.* [3] reported that training, which involves plyometrics exercises, is an effective method for enhancing power for COD movements. Plyometrics is a term which is used to describe jump-based exercises designed to enhance leg qualities, such as power and reactive strength, and which utilise the stretch shortening cycle (SSC) [4-7]. Leg qualities are considered to be important to the performance of various sporting tasks [8, 9]. For example, Delecluse *et al.* [10] and Rimmer and Sleivert [9] report that plyometric training, combined with appropriate sprint training, enhances acceleration over the first 10m of a sprint effort. Further to this, it has also been reported that vertical jump height improves following plyometrics training [4, 11, 12].

The SSC is a naturally occurring mechanism which involves a stretching of a musculotendinous unit immediately prior to a fast concentric contraction, resulting in an increased production of force [13]. The coupling of an eccentric and a concentric contraction allows for a muscle contraction to express a greater force and be more powerful than a concentric contraction in isolation [7, 14]. This can be attributed to a number of factors such as increased active state of the muscle [15], stretch reflex [13], the storage and reutilisation of elastic energy [7, 16, 17] and preactivation of the muscle during the eccentric phase [7, 18]. According to Fleischmann *et al.* [1], movements containing a vertical application of force, such as the counter movement jump, are actions which exhibit the classical model of the SSC. Schmitdbleicher [19] suggested that the SSC can be categorised as ‘fast’ or ‘slow’ depending on ground contact time (GCT), a factor which is of great relevance in agility and COD movements [20], angular joint displacement and contraction time. The drop jump is classified as a fast SSC movement due to short GCT (<0.250 seconds), small angular displacements of the hip, knee and anterior ankle angle and fast contraction times (<0.250 seconds) [7]. Conversely, the countermovement jump has contraction and GCT which are greater than 250 milliseconds and larger displacements of the hip, knee and anterior ankle angles, therefore it is viewed as a slow SSC exercise [7]. It must be emphasised, however, that some GCT's can be too short in duration for an athlete to produce large quantities of force [21]. The nature of the SSC in a movement, and also the aim of a plyometric exercise, allows for enhanced force production [13]. Therefore, these movements must have an adequate contact time with the ground to produce the required forces.

COD movements, such as lateral movements, cannot be adequately described by the classical model of the SSC, as the model is not sufficient [1]. Furthermore, according to Fleishmann *et al.* [1], these movements are difficult to control when compared biomechanically to the classic SSC model. Mack [22] stated that this difficulty is due to the musculature in the ankle complex. This musculature is known to provide stabilisation of the ankle joint during movement performed in the sagittal plane in both dorsi- and plantar-flexion, yet not in movements such as lateral jump exercises, in the frontal plane [22]. An increase in the distance of a lateral jump is shown to increase GCT's and create a greater dependency on the hip and knee and less of a contribution from the musculature of the ankle complex, lowering the usage of the SSC [1]. This is likely due to the protective mechanism provided by the Golgi Tendon Organ(GTO), located in the extra fusal fibres [23], which detects changes in tension in the musculotendinous unit and facilitates a contraction in the antagonist muscle, where required [7, 24].

Currently, no studies have quantified, in detail, changes to hip, knee and the anterior and medial ankle joint angles as the distance of a lateral jump increases. As stated previously, a greater displacement of the hip, knee and ankle joints indicates a greater contribution of the musculature around these joints to perform the exercise. This consequently suggests less of a contribution from the SSC as the larger muscles across multiple joints contribute to the desired movement outcome.

The purpose of this study was to examine, over a number of different distances, a type of unilateral jump that is currently used in COD plyometric training. The aim of the study was to quantify the changes in joint angles at three different joints (hip, knee and anterior ankle) and to confirm if there is a significant difference between the angles at different distances. A large displacement of these joints indicates a lack of leg stiffness, a key component of the SSC, consequently meaning that the exercises could not be classed as a 'fast plyometric exercise'. It is hypothesised that, as the distance jumped increases, the angular displacement at each joint measured will increase, as will GCT.

2. Methodology

2.1. Participants

Eight healthy participants aged 23.75±3.11 completed the testing procedure. Both male (n=7) and female (n=1) athletes participated. Each athlete had either current or previous experience of plyometric exercises and plyometric training and also experience of CODS sport performance. Inclusion criteria for participants necessitated that a minimum of 12 months experience in plyometric training and CODS sport performance. Participants completed a Physical Activity Readiness Questionnaire (PAR-Q) and signed an informed consent form, after having read the provided participant information sheet detailing the study. The aforementioned documents were all approved by the Cardiff Metropolitan University Research and Ethics Committee. Participants were able to withdraw from the study at any point.

Table1. *Descriptive statistics of the group population*

Descriptive Statistic	Mean ± SD
Age (Years)	23.75±3.11
Stature (cm)	177.63 ± 6.46
Mass (kg)	77.76 ± 10.91

2.2. Data Collection

2.2.1. Jumping Procedure

Data collection took place at the National Indoor Athletics Centre, situated at Cardiff Metropolitan University in Cardiff, Wales. Participants were requested to attend two sessions within a seven-day period of each other. During the first session, the participants were familiarised with the procedure in order to confirm safe and competent jumping technique and reduce the learning effect during the data collection session. The second session consisted of the data collection protocol. All participants were requested to perform a RAMP warm up procedure in-line with Jeffreys' [25]. Following this, the athletes performed a lateral plyometric exercise on both left and right legs using a randomized counter-balanced design. Participants would begin standing on one foot at a distance of either 0.25m, 0.50m, 0.75m or 1.00m (Figure 1.) and upon command, jump laterally on to a target with their opposite foot landing upon a highly visible line on the ground. Subsequently, participants were requested to jump back in the direction they had come from to a target 1.00m away onto their starting foot as quickly as possible, whilst maintaining the correct technique specified by Flanagan and Comyns [7]. Participants were required to land with the floor marker running directly through the middle of the foot from toe to heel. If the marker was missed, the jump was discarded and performed again. Each participant performed 24 jumps in total comprising of 12 on each leg, with three attempts at each of the four distances. The distances were measured using a metal tape measure and were marked on the floor using a brightly coloured tape.

2.2.2. Kinematic Data

Kinematic data was collected using a slow-motion setting of the camera from an Apple iPad (Apple Inc., Cupertino, CA, USA) mounted on a tripod, filming at 240fps. The camera was positioned to permit joint data collection in the sagittal plane (Figure 1.). Each of the 24 jump trials were individually filmed. Videos were then cropped to length using Kinovea v0.8.15. Each video trial was subsequently digitised from the point of foot ground contact to the point of toe-off using Quintic Biomechanics v29. (Quintic Consultancy Ltd., Sutton Coldfield, West Midlands, UK). The digitisation template used permitted for the placing of markers at the shoulder, hip, knee, ankle and the joint of the little toe, allowing for variables to be calculated for the hip, knee and ankle joints respectively.

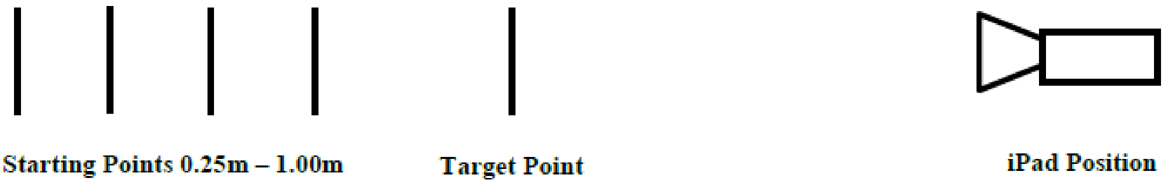

Figure1. *A representation of the jumping distances and the iPad camera position in relation to the kinematic data capture area*

2.2.3. Data Analysis

Following digitisation, all data was transferred into Microsoft Excel (Microsoft Corporation, Redmond, WA, USA). Calculations were made for minimum angle at the hip, knee and ankle and angular displacement. GCT was also recorded. Joint displacement was calculated by subtracting the minimum angle from the initial angle upon ground contact (Equation1.0).

$$\theta - \theta^{Min}$$

Equation 1.0

Averages and standard deviations were calculated for the entire population for all angles and distances for each variable. Further statistical analysis between variables at each joint angle and distance jumped was completed using IBM SPSS Statistics v25 (IBM Corporation, Armonk, NY, USA). A Shapiro-Wilkes test confirmed normality for each joint angle and limb ($P < 0.05$). A Mauchly's test for sphericity was also completed. Where data was observed to have violated the assumptions of sphericity, a Greenhouse-Geisser correction was applied. Finally, for all variables, a one-way analysis of variance (ANOVA) with repeated measures was utilised in order to determine whether there was a significant difference between the values at each distance jumped. A Bonferroni post hoc test was used to evaluate all differences between the jump distances.

3. Results and Discussion

Mean values, range and 95% confidence levels for each distance and each leg are reported for GCT (Table 2.), the hip, knee and ankle joints for minimum angle (Table 3.) and the hip, knee and ankle for joint displacement (Table 4.).

The results of the one-way repeated measures ANOVA revealed a significant difference ($P < 0.05$) between GCT for jumps on the right leg; the left leg was found to have no significant difference ($P > 0.05$) across all jumping distances. No significant difference in minimum angle at each distance was found, on either leg, for the hip joint. Significant differences were discovered for the ankle on the right leg and the knee on the left leg, yet no significant difference at each of the joints on the opposing leg. Angular displacement displayed significant differences between the jumping distances at each joint on each leg, except for the hip joint on the left foot; this was found to have no significant difference.

Table2. *Ground Contact Times (s) mean ± SD, range and 95% confidence levels for each jump distance*

Landing Foot	**Left Foot**				**Right Foot**			
Jump Distance (m)	0.25	0.50	0.75	1.00	0.25	0.50	0.75	1.00
Mean ± SD (s)	0.310 ± 0.048	0.299 ± 0.036	0.283 ± 0.030	0.327 ± 0.051	0.306 ± 0.044	0.293 ± 0.041	0.307 ± 0.055	0.338 ± 0.062
Range (s) (Max; Min)	0.158 (0.372; 0.214)	0.097 (0.328; 0.231)	0.089 (0.325; 0.236)	0.119 (0.397; 0.278)	0.133 (0.372; 0.239)	0.117 (0.364; 0.247)	0.183 (0.411; 0.228)	0.197 (0.453; 0.256)
95% Confidence Levels Lower Limit : Upper Limit	0.270 : 0.350	0.270 : 0.329	0.257 : 0.309	0.284 : 0.370	0.270 : 0.343	0.259 : 0.327	0.262 : 0.353	0.286 : 0.390

Table3. *Minimum Angle (°) mean ± SD, range and 95% confidence levels for each jump distance and joint*

	Landing Foot	**Left Foot**				**Right Foot**			
Hip	Jump Distance (m)	0.25	0.50	0.75	1.00	0.25	0.50	0.75	1.00
	Mean ± SD(°)	127.23 ± 8.22	127.35 ± 8.83	132.29 ± 9.63	131.08 ± 6.90	125.29 ± 9.46	125.92 ± 10.87	129.86 ± 8.21	129.61± 8.54
	Range (°) (Max; Min)	22.49 (139.05; 116.56)	23.93 (138.56; 114.63)	29.34 (145.95; 116.61)	22.14 (137.69; 115.55)	28.07 (138.13; 110.07)	32.52 (138.24; 105.72)	29.37 (144.70; 115.34)	25.71 (138.78; 113.07)
	95% Confidence Levels Lower Limit : Upper Limit	120.35 : 134.11	119.97 : 134.73	124.24 : 140.34	125.31 : 136.84	117.38 : 133.20	116.83 : 135.01	122.99 : 136.72	122.47 : 136.75
Knee	Landing Foot	**Left Foot**				**Right Foot**			
	Jump Distance (m)	0.25	0.50	0.75	1.00	0.25	0.50	0.75	1.00
	Mean ± SD(°)	121.52 ± 4.34	123.87 ± 4.38	128.39 ± 6.11	124.66 ± 5.22	122.57 ± 4.19	123.38 ± 2.72	124.29 ± 2.37	121.43± 3.33
	Range (°) (Max; Min)	12.26 (128.48; 116.22)	13.46 (128.78; 115.32)	19.45 (135.99; 116.54)	15.32 (132.68; 117.36)	10.90 (128.26; 117.36)	8.88 (126.59; 117.72)	7.14 (127.93; 120.9)	10.56 (126.85; 116.29)
	95% Confidence Levels Lower Limit : Upper Limit	117.90 : 125.15	120.20 : 127.53	123.28 : 133.49	120.30 : 129.02	119.07 : 126.07	121.10 : 125.65	122.31 : 126.28	118.65 : 124.21
Ankle	Landing Foot	**Left Foot**				**Right Foot**			
	Jump Distance (m)	0.25	0.50	0.75	1.00	0.25	0.50	0.75	1.00
	Mean ± SD(°)	77.83 ± 2.28	79.47 ± 3.44	81.45 ± 5.27	80.30 ± 5.11	79.81 ± 4.09	83.05 ± 2.25	83.57 ± 5.05	82.89 ± 4.49
	Range (°) (Max; Min)	6.80 (81.08; 74.28)	9.47 (85.55; 76.08)	16.34 (90.16; 73.82)	14.28 (89.51; 75.23)	11.98 (85.01; 73.04)	6.98 (86.05; 79.07)	11.62 (89.33; 77.71)	10.94 (88.73; 77.79)
	95 % Confidence Levels Lower Limit : Upper Limit	75.92 : 79.74	76.60 : 82.35	77.04 : 85.86	76.02 : 84.57	76.39 : 83.23	81.16 : 84.93	79.35 : 87.80	79.13 : 86.64

Table4. *Angular displacement (°) mean ± SD, range and 95% confidence levels for each jump distance and joint*

	Landing Foot	**Left Foot**				**Right Foot**			
Hip	Jump Distance (m)	0.25	0.50	0.75	1.00	0.25	0.50	0.75	1.00
	Mean± SD(°)	12.80 ± 5.04	13.17 ± 2.41	9.79 ± 2.27	15.33 ± 4.66	14.60 ± 7.02	14.73 ± 6.72	14.02 ± 3.90	17.76 ± 6.10
	Range (°) (Max; Min)	13.36 (19.55; 6.19)	7.84 (16.70; 8.86)	7.35 (13.38; 6.03)	12.94 (21.56; 8.62)	18.65 (24.55; 5.90)	17.51 (26.42; 8.91)	11.11 (18.55; 7.44)	17.92 (27.85; 9.89)
	95 % Confidence Levels Lower Limit : Upper Limit	8.59 : 17.01	11.15 : 15.18	7.89 : 11.68	11.44 : 19.22	8.11 : 21.09	8.52 : 20.94	10.41 : 17.63	12.12 : 23.40
Knee	Landing Foot	**Left Foot**				**Right Foot**			
	Jump Distance (m)	0.25	0.50	0.75	1.00	0.25	0.50	0.75	1.00
	Mean± SD(°)	18.95 ± 5.30	18.57 ± 4.26	17.60 ± 3.95	24.41 ± 5.68	17.71 ± 5.76	18.97 ± 5.21	23.77 ± 4.90	26.72 ± 7.39

	Range (°) (Max; Min)	18.38 (26.51; 8.13)	10.59 (24.53; 13.94)	11.41 (24.00; 12.59)	14.89 (31.24; 16.35)	15.27 (28.01; 12.74)	15.88 (26.48; 10.60)	14.74 (31.73; 16.97)	21.63 (35.92; 14.30)
	95% Confidence Levels Lower Limit : Upper Limit	14.52 : 23.38	15.01 : 22.13	14.29 : 21.00	19.66 : 29.16	12.90 : 22.53	14.62 : 23.33	19.68 : 27.87	20.54 : 32.90
Ankle	Landing Foot	**Left Foot**				**Right Foot**			
	Jump Distance (m)	0.25	0.50	0.75	1.00	0.25	0.50	0.75	1.00
	Mean ± SD(°)	22.68 ± 3.16	24.35 ± 4.14	26.98 ± 4.87	31.41 ± 5.85	22.69 ± 5.66	24.12 ± 3.22	29.34 ± 3.27	34.14 ± 4.13
	Range (°) (Max; Min)	9.86 (28.79; 18.93)	11.43 (30.24; 18.81)	14.53 (31.19; 16.66)	19.95 (40.24; 20.29)	15.85 (29.60; 13.75)	10.10 (28.80; 18.70)	8.22 (33.86; 25.64)	11.43 (39.89; 28.46)
	95% Confidence Levels Lower Limit : Upper Limit	20.03 : 25.32	20.89 : 27.82	22.90 : 31.05	26.52 : 36.31	17.95 : 27.43	21.43 : 26.81	26.61 : 32.07	30.69 : 37.59

This study set out with the purpose of investigating unilateral jumps performed at different distances. Seven variables were analysed in order to highlight any differences which may occur as unilateral jumping distance increases. It was hypothesised that, for GCT, as the jumping distance increased, so would the time in which the athlete was in contact with the ground. This was not clearly reflected in the results with the left leg showing no significant difference between the jumping distances. However, it was revealed in the results that the right leg jumping distances were significantly different, although the shortest jumping distance did not have the lowest GCT. A trend was noted that 0.50m distance had the lowest mean value and range of all distances, on both jumping legs; however, using the thresholds suggested by Schmitdbleicher [19], all jump distance means fell into the slow SSC category, with all values being greater than 0.250s. Fleischmann *et al*. [1] claimed that the ankle complex, during lateral movements, is at a disadvantage due to the lack of a large muscle-tendon complex running laterally over the joint; this may explain the long GCT's observed in this study. A possible explanation for the 0.50m distance having a shorter GCT than 0.25m, may be partly due to anticipatory pre-activation and/or the central motor programme, which act to prevent the collapse of a joint directly after contact with the ground [26-27]. The pre-activation of the muscle, prior to ground contact, at the 0.25m distance may not be great enough due to the low height from which the athlete comes into contact with the ground, lessening the pre-activation of the muscle and consequently meaning an increased GCT, caused by a longer amount of time required to produce force [21]. Furthermore, Bobbert, Gerritsen, Litjens and Van Soest [15] stated that greater active state of the muscle contributes to the greater expression of force viewed in the SSC.

Interestingly, the minimum angle values showed no significant difference between the jumping distances, except for the right ankle and left knee joints. The mean values indicated an increase in the minimum joint angle as the jump distance increased, a result which was not expected. However, significant differences for joint displacement were found to be present between all jumping distances and joints, except for the left hip joint. Greater joint displacement indicates a greater contribution to force production from the musculature surrounding the hip and knee joints and less of a contribution from the SSC, as stiffness in the knee extensor is associated with regulation of muscle power and performance in jumping exercises [27]. Nevertheless, it was interesting to note that only the ankle joint, on both legs, and right knee joint mean values revealed an increase in displacement as the jumping distance increased. At the hip joint, the 0.75m distance was seen to have the least angular displacement; this was the same at the left knee joint. Larger displacements may be explained by the initial ingle of each joint up on contact with the ground. It is most likely that, as distances increase, the athletes' hip, knee and ankle joints are at a greater length of extension than at shorter distances; likely caused by a greater jump height required in order to reach the target mark from greater distances.

In-line with GCT, larger displacements may be explained by the production of a larger force from the hip and knee musculature; however, this is a notion which requires further research. Although, at the hip and left knee joints, mean values were lowest at the 0.75m distance, these levels of angular displacement still indicate that muscle stiffness, a key component of the SSC [7], was not maintained throughout the process of each jump, at each joint and distance. However, research by Maffiuletti *et al*. [28] states that muscle tension prior to an explosive contraction can reduce the rate of force development (RFD) generated by the muscle due to the discharge pattern of the motor unit.

This may explain some of the lack of stiffness at the hip, knee and ankle joint during lateral jumps as distance traversed increases. The eccentric stretching of the muscle which occurs in the SSC [13] may cause this stiffness of the muscle prior to ground contact; therefore, due to the reduction in RFD as a result of stiffness in the muscle caused by the nature of the SSC, upon ground contact, the musculature of the knee and hip are required to contribute a greater production of force in order to counter the downwards movement of the body upon landing, consequently increasing joint displacement. This notion is reinforced by the force-length relationship of a muscle, as greater forces are produced by muscles when they are at the mid-length [29]. These findings give further evidence to support Fleischmann *et al*. [1] and their theory that the ankle complex is at a disadvantage during lateral movements.

The findings of this study indicate that lateral jumping exercises cannot be classed as a fast-plyometric exercise, as they do not display characteristics such as leg stiffness, small joint displacements and short GCTs (<0.250s) [7,19]. It should be noted, however, that some participants' data indicated that a fast- plyometric exercise had been performed at a number of the distances, whereas some were a significant margin over the threshold of 0.250s. This was also observed with joint displacement values. Additionally, the findings of this study are consistent with Flanagan & Comyns' [7] notion of individualisation. This has implications for coaches when implementing a training programme, as they must be attentive of the fact that individual athletes may find that certain jumping distances provide too much overload on landing to initiate a GCT within the parameters outlined by Schmidtbleicher [19]. Although GCT was, on average, found to be greater than the threshold suggested by Schmidtbleicher [19] of 0.250s for fast-plyometric exercises, some research has previously indicated that the upper threshold of the timeframe to produce a peak force is a GCT of 0.8s [30].

CODS performance is reported to regularly display low GCT and low angular joint displacements [20]. The findings of this study have highlighted that lateral jumping exercises are not representative of CODS movements. Therefore, it is imperative that coaches implement these exercises with the aim of increasing peak force production, rather than as a plyometric exercise to improve CODS performance.

4. Conclusion

The purpose of this study was to analyse the kinematics of a mode of unilateral jump. The aim was to quantify the angular changes which occur at the hip, knee and ankle joints and to analyse the effect of increasing jump distance on GCT. The results reveal that GCT, for each distance on the right foot, was statistically significantly different ($P<0.05$); however, results for the left foot were not ($P>0.05$). The results of the statistical analysis of minimum angle revealed significant differences at the right ankle and left knee; no difference was found at the joints on the opposing legs, nor for either leg at the hip joint. Angular displacement was observed to be statistically significantly different at all joints, excluding the left hip. Group means indicate that this particular lateral jumping activity is not representative of CODS movement in sport [20], therefore practitioners may wish to apply the results of this study, in order to make an informed decision on exercise selection.

References

[1] Fleischmann, J., Gehring, D., Mornieux, G. and Golhofer, A. Load-dependent movement regulation of lateral stretch shortening cycle jumps. EurJApplPhysiol.110.177-187(2010)

[2] Mornieux, G., Gehring, D., Tokuno, C., Gollhofer, A. and Taube, W. Changes in leg kinematics in response to unpredictability in lateral jump execution. *European Journal of Sport Science*. Vol. 14, No. 7, 678–685(2014).

[3] Miller, M.G., Herniman, J.J., Ricard, M.D., Cheatham, C.C. and Michael, T.J. The effects of a 6-week plyometric training program on agility. *Journal of sports science & medicine*, *5*(3), p.459(2006).

[4] de Villarreal, E.S.S., Kellis, E., Kraemer, W.J. and Izquierdo, M. Determining variables of plyometric training for improving vertical jump height performance: a meta-analysis. *The Journal of Strength & Conditioning Research*, *23*(2), pp.495-506(2009).

[5] Fatouros, I.G., Jamurtas, A.Z., Leontsini, D., Taxildaris, K., Aggelousis, N., Kostopoulos, N. and Buckenmeyer, P. Evaluation of plyometric exercise training, weight training, and their combination on vertical jumping performance and leg strength. *The Journal of Strength & Conditioning Research*, *14*(4), pp.470-476(2000).

[6] Thomas, K., French, D. and Hayes, P.R. The effect of two plyometric training techniques on muscular power and agility in youth soccer players. *The Journal of Strength and Conditioning Research*, *23*(1), pp.332-335(2009).

[7] Flanagan, E.P. and Comyns, T.M. The use of contact time and the reactive strength index to optimize fast stretch-shortening cycle training. *Strength & Conditioning Journal*, *30*(5), pp.32-38(2008).

[8] Sheppard, J. and Young, B. Agility literature review: classifications, training and testing. *Journal of Sports Science*. *24 (9)*, 919-32(2006).

[9] Rimmer, E. and Sleivert, G. Effects of a Plyometrics Intervention Program on Sprint Performance. *The Journal of Strength & Conditioning Research*, *14*(3), pp.295-301(2000).

[10] Delecluse, C., Van, H.C., Willems, E., Van, M.L., Diels, R. and Goris, M. Influence of high- resistance and high-velocity training on sprint performance. *Medicine and science in sports and exercise*, *27*(8), pp.1203-1209(1995).

[11] Adams, K., O'Shea, J.P., O'Shea, K.L. and Climstein, M. The effect of six weeks of squat, plyometric and squat-plyometric training on power production. *Journal of applied sport science research*, *6*(1), pp.36-41(1992).

[12] Brown, M.E., Mayhew, J.L., and Boleach, L.W. Effect of plyometric training on vertical jump performance in high school basket ball players. *J Sport Med Phys Fitness*, *26*, pp.1-4(1986).

[13] Komi, P.V. Stretch-shortening cycle: a powerful model to study normal and fatigued muscle. *Journal of biomechanics*, *33*(10), pp.1197-1206 (2000).

[14] Komi, P.V. Stretch-shortening cycle. *Strength and power in sport*, *2*,pp.184-202(2003).

[15] Bobbert, M.F., Gerritsen, K.G., Litjens, M.C. and Van Soest, A.J. Why is countermovement jump height greater than squat jump height?. *Medicine and science in sports and exercise*, *28*, pp.1402-1412(1996).

[16] Cavagna, G.A., Dusman, B. and Margaria, R. Positive work done by a previously stretched muscle. *Journal of applied physiology*, *24*(1), pp.21-32(1968).

[17] Komi, P.V. and Bosco, C. Utilisation of stored elastic energy in leg extensor muscles in men and women. *Med Sci Sports Exerc.*, 10, pp.261-265(1978).

[18] Schenau, G.J.V.I., Bobbert, M.F. and de Haan, A. Does elastic energy enhance work and efficiency in the stretch-shortening cycle?. *Journal of applied biomechanics*, *13*(4), pp.389-415 (1997).

[19] Schmidtbleicher, D. Training for power events. *Strength and power in sport*, *1*, pp.381-395 (1992).

[20] Barnes, J., Schilling, B., Falvo, M., Weiss, L., Creasy, A. and Fry, A. Relationship of jumping and agility performance in female volleyball athletes. *Journal of Strength and Conditioning Research*. 21, 1192–1196(2007).

[21] Kawamori, N., Rossi, S., Justice, B., Haff, E., Pistilli, E., O'Bryant, H., Stone, M. and Haff, G. Peak force and rate of force development during isometric and dynamic mid-thigh clean pulls performed at various intensities. *Journal of Strength and Conditioning Research*. 20,483–491 (2006).

[22] Mack, R. Ankle injuries in athletics. *Clinical Sports Medicine*.1,71–84(1982).

[23] Riemann, B.L. and Lephart, S.M. The sensorimotor system, part I: the physiologic basis of functional joint stability. *Journal of athletic training*,*37*(1),p.71(2002).

[24] Lephart, S.M., Pincivero, D.M., Giraido, J.L. and Fu, F.H. The role of proprioception in the management and rehabilitation of athletic injuries. *The American journal of sports medicine*, *25*(1), pp.130-137(1997).

[25] Jeffreys, I. Warm-up revisited: The ramp method of optimizing warm-ups. *Professional Strength and Conditioning*. (6) pp.12-18(2007).

[26] Melvill Jones, G. and Watt, D. G. D. Observation on the control of stepping and hopping movements in man. *J Physiol*, (219), pp.709-727(1971).

[27] Horita, T., Komi, P., Nicol, C. and Kyröläinen, H. Interaction between pre-landing activities and stiffness regulation of the knee joint musculoskeletal system in the drop jump: implications to performance. *European journal of applied physiology*, *88*(1-2), pp.76-84 (2002).

[28] Maffiuletti, N., Aagaard, P., Blazevich, A., Folland, J., Tillin, N. and Duchateau, J. Rate of force development: physiological and methodological considerations. *European Journal of Applied Physiology*, 116, pp.1091-1116(2016).

[29] Rassier, D.E., MacIntosh, B.R. and Herzog, W. Length dependence of active force production in skeletal muscle. *Journal of applied physiology*, *86*(5),pp.1445-1457(1999).

[30] Turner, A. and Jeffreys, I. The stretch shortening cycle: Proposed mechanisms and methods for enhancement. *Strength and Conditioning Journal*, 32(4),pp.87-99(2010).

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