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ORIGINAL RESEARCH

The effect of a 6-week plyometric training on agility, jump height, and dynamic balance in young artistic and rhythmic gymnasts

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Abstract

Background: Artistic gymnastics (AG) and rhythmic gymnastics (RG) are sports characterized by rapid contraction of muscles in the lower limbs while performing skills, requiring a high level of physical fitness. Agility, strength and balance are some of the basic abilities for successful performance. **Objective:** The purpose of the study was to examine the effect of a 6-week plyometric training on agility, jump height, and dynamic balance in young artistic and rhythmic gymnasts. **Methods:** Forty-eight young female gymnasts, aged 9 to 11, participated in the study. They were divided into two equal groups, experimental (EG) and control (CG). The EG participated in a 6-week plyometric training (PT) in addition to a conventional training program. **Results:** A 2 (sport) × 2 (group) × 2 (time) analysis of variance was used to examine the effects and their interactions for sport (RG × AG), group (EG × CG) and time (pre × post) on the dependent variables for agility, jump height, and dynamic balance. Statistical analysis showed a significant group effect of time and significant group × time interaction for all dependent variables. **Conclusions:** Results revealed that 9–11-year-old female artistic and rhythmic gymnasts may be greatly benefited by PT. In fact, it appears that traditional gymnastics training completed with a supervised and well-designed PT protocol may lead to improving motor abilities directly related to the performance of routines in female gymnasts in RG and AG compared to gymnastic practice alone in this age group.

Keywords: agility, balance, vertical jump, gymnastics, plyometrics

Introduction

Artistic gymnastics (AG) in many cases is characterized by rapid muscle contractions, combined with the balance and agility of muscles in the lower limbs during performance of acrobatic elements. Rhythmic gymnastics (RG) is characterized by high demands on coordination, agility, jumping, balance and interaction between body and apparatus. Agility is demonstrated when performing floor exercises, particularly by female gymnasts, when they alter the direction of their body's movement on the floor space paired with music. Both sports require a high level of physical fitness and mastery of skills to succeed (Bradshaw & Le Rossignol, 2004; Daly et al., 2001; Lindner et al., 1991). Previous studies indicate that there are differences between high and non-high-level gymnasts in jumping ability (Batista et al., 2017). Another study revealed that 4–8 weeks of plyometric training (PT) improve jump performance (Bogdanis et al., 2019; Marina & Jemni, 2014; Nitzsche et al., 2022). PT improves athletes' explosive strength and jumping ability, enhancing muscle force and power production through the stretch-shortening cycle (SSC) of the muscle unit (Fatouros et al., 2000) and change of direction (CoD) ability (Asadi et al., 2017). The SSC is characterized by a rapid transition between the initial eccentric "stretch" and subsequent concentric "recoil" (Komi, 2000; Marina & Jemni, 2014). The SSC entails the storage of elastic energy during the initial stretch, which contributes to the potentiation of force during the subsequent shortening of the muscle (Komi, 2003).

In AG and RG athletes move rapidly in different directions in the space performing a variety of dance and choreographic movements, an ability known as agility, which is marked by rapid CoD in response to a stimulus (Sheppard & Young, 2006) and refers to a movement where is preplanned to be performed and is influenced by physical parameters such as strength, power and speed (Yap & Brown, 2000). This ability is dependent on several factors and inputs including physical, cognitive, and technical elements (Sheppard & Young, 2006). As Spiteri et al. (2014, p. 2415) stated, "an athlete's ability to shift their momentum during directional changes requires sufficient eccentric (braking), isometric (plant phase), and concentric (propulsive) strength to rapidly decelerate and reaccelerate in the new direction".

PT is a recognized training method that improves performance in sports where explosive strength and power are expressed (Dallas et al., 2018, 2023; Markovic et al., 2007; Miller et al., 2006).

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Different training methods, such as resistance training, or PT, as well as a combination of PT and resistance training, have been applied to examine their effect on CoD (Arazi et al., 2014; Faigenbaum et al., 2007). Previous studies have suggested that PT is a safe and effective method for improving physical abilities in young athletes (Dallas et al., 2020; Lloyd et al., 2011).

According to Malina et al. (2004), motor performance increases until the age of 13 or 14 in girls, but after that, there is only slight improvement. Further, youths between 10 and 11 years of age showed accelerated SSC development, a phenomenon that continued near the time of peak height velocity (Lloyd et al., 2011).

In floor event, gymnasts move at velocity while simultaneously changing direction within the space. For this reason, the improvement of dynamic balance, which is not fully mature and in a maturation stage (Payne & Isaacs, 2005), should be a key component in training programs for young athletes aimed at improving athletic performance and subsequent their development at a high level (Lloyd et al., 2015). Effective performance of agility presupposes a satisfactory level of dynamic balance, which should compensate and adapt as the practitioner's rapid CoD could repeatedly shift the center of gravity off the base of support (Kibele et al., 2015). According to previous studies, agility training is considered to be an enhancement of motor programming through neuromuscular conditioning and neural adaptation of muscle spindles, Golgi tendon organs, and joint proprioceptors (Craig, 2004). So, agility training, balance training and PT are the main elements of the model proposed by Granacher et al. (2016) in the training process during long-term athlete development. Further, greater enhancements in agility are seen using PT with a horizontal component (Salonikidis & Zafeiridis, 2008), whereas greater jump height can be achieved with both horizontal and vertical components (King & Cipriani, 2010).

Although PT is applied in almost all sports to improve performance parameters, little attention was paid to determining if PT actually enhances agility, strength and dynamic balance in young female gymnasts. Therefore, the purpose of the present study was to examine the effect of 6-week PT on the aforementioned variables in young artistic and rhythmic gymnasts. The research hypothesis was that the intervention/experimental group (EG) in both sports would outperform the control group (CG).

Methods

Participants

A total of 48 female gymnasts aged 9 to 11 years, with no musculoskeletal injuries in the previous 6 months, participated in the study. The study involved club athletes from two sports, AG and RG. Therefore, it was known to the researchers which sport each athlete belonged to. Based on their age category, each gymnast participated in their nation's official competition responsibilities (compulsory routines) and was enrolled in the Federation's sports register. The gymnasts were divided into two groups: EG (n = 24) and CG (n = 24). Half of the gymnasts from each group were artistic gymnasts and the other half were rhythmic gymnasts. The mean age of groups was 10.63 ± 1.31 and 10.63 ± 1.21 years, body height 1.44 ± 0.10 and 1.45 ± 0.11 m, body mass 35.82 ± 6.82 and 39.75 ± 10.25 kg, with a mean training experience 4.42 ± 1.35 and 4.50 ± 1.41 years for EG and CG, respectively.

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Ethics committee of the Faculty of Physical Education and Sport Science, of the National and Kapodistrian University of Athens (1376/20-04-2022). Prior to the study, procedures and guidelines were presented orally and in written form. All participants' parents gave written informed consent before participating in any of the testing. The participants were informed extensively about the experiment procedures and the possible risks or benefits of the project.

Training programme

The EG participated in a 6-week PT in addition to the traditional training program in order to determine whether can directly affect agility, jump height and dynamic balance (Table 1). Both the rest between sets and between exercises lasted thirty seconds. The gymnasts took a 72-hr rest in between each of their two weekly training sessions. This intervention period was chosen considering that physiologically and psychologically is the optimal length of time for the central nervous system to be stressed without excessive strain or fatigue (Adams et al., 1992). PT volume is typically quantified as the number of foot contacts per session. During the training period, all participants were under direct supervision and were instructed on how to perform each exercise.

Table 1 A 6-week intervention plyometric training program

	1st week		2nd week		3rd week		4th week		5th week		6th week	
Training unit	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th
Double tuck jumps	2 × 6		2 × 8		2 × 10	2 × 12	3 × 10		3 × 12	1 × 10	3 × 10	2 × 10
Counter drop jump	2 × 8		2 × 8		2 × 10		3 × 8		3 × 10	1 × 10	3 × 12	2 × 10
Lateral hops		3 × 8		3 × 10	3 × 12		3 × 12	3 × 15	1 × 8	3 × 15	2 × 10	1 × 20
Single leg bench jump (for each leg)	2 × 6		2 × 8			2 × 8		2 × 8	1 × 8	2 × 8		2 × 10
Single lateral jumps		3 × 8		3 × 8		3 × 10		2 × 12	1 × 12	2 × 12	2 × 12	3 × 12
Alternating lunges	2 × 6	1 × 8	2 × 8	2 × 8		2 × 8		2 × 8	2 × 10	2 × 8	2 × 8	2 × 10
Total contacts	52	56	64	70	76	86	90	101	114	121	126	136

Testing procedure

Agility was determined with the T-test, which is a simple fitness test measuring how quickly a direction can be changed accurately. The score was recorded to the nearest 0.01 s.

Squat jump height (Bosco et al., 1983) was obtained with the Chronojump 2.3.0-1607 mat (Chronojump-Boscosystem, Barcelona, Spain), calculated from flight time duration. Each participant performed two trials with a 1-min rest interval and the best trial was used for statistical analysis.

Dynamic balance was measured using the Y-Balance Test, which is a variant of the Star Excursion Balance Test (Butler et al., 2013). After the leg length was measured from the greater trochanter to the outer malleus), the athletes performed three test attempts on each leg separately. The best score was used for further statistical analysis.

The same procedure was repeated immediately after the end of the intervention program.

Statistical analysis

The statistical analysis was done with IBM SPSS Statistics for Windows (Version 24; IBM, Armonk, NY, USA). To analyze the data, the 2 (sport) × 2 (group) × 2 (time) ANOVA method was used to examine the effects and their interactions for the factors: sport (RG × AG), group (EG × CG) and time (pre × post) on the dependent variables (agility, jump height, dynamic balance). Normality of the data was checked and subsequently confirmed using the Kolmogorov-Smirnov test. If significant main effects or interactions were present, the Tukey HSD post hoc test was used to identify specific differences. The level of significance was set at $p < .05$.

Results

Agility

Descriptive statistics are presented in Table 2. No significant interaction effect between the three factors (sport × group × time) on agility was found. However, a significant interaction effect was found between groups (EG × CG) × time (pre × post), $F(2) = 34.02$, $p < .001$. A significant main effect was found of time ($F(1) = 81.52$, $p < .001$), but not of group ($F(1) = 1.23$, $p = .274$). Accordingly, the interaction was examined and the Tukey post hoc test showed significant differences between post-measurements ($p = .001$).

Jump height

Descriptive statistics are presented in Table 2. No significant interaction effect between the three factors (sport × group × time) on jump height was found. However, a significant interaction effect was found in group (EG × CG) × time (pre × post), $F(2) = 25.25$, $p < .001$. Also, a significant main effect was found in time ($F(1) = 36.52$, $p < .001$), but not in group ($F(1) = 0.636$, $p = .430$). Accordingly, the interaction was examined and the Tukey post hoc test showed significant differences between post-measurements ($p < .001$).

Dynamic balance

Descriptive statistics are presented in Table 2. According to the results, there was no statistically significant interaction between the three factors (sport × group × time) of dynamic balance ($F(2) = 2.04$, $p = .161$) However, a significant interaction was found of group × time (F (1) = 28.09, $p < .001$). Also, a significant main effect was found in time ($F(1) = 51.88$, $p < .001$). Accordingly, the interaction was examined and the Tukey post hoc test showed significant differences between the post-measurements ($p < .001$).

Discussion

The effect of six weeks of PT, in addition to regular gymnastics training, on agility, jump height and dynamic balance was examined in young artistic and rhythmic gymnasts using a repeated measures design. The main findings of this study were that artistic and rhythmic gymnasts may benefit from a 6-week PT that is integrated with their usual gymnastics practice by improving the examined variables. More precisely, our findings showed that including an integrated functional PT into routine AG and RG training resulted in a better degree of progress than they would obtain from purely gymnastic-specific training confirming our initial hypothesis that the interventional PT would outperform the conventional training program and result in even greater improvement.

Table 2 Means, standard deviations, and the effect of group × time interaction for agility, jump height, and dynamic balance

Test/Sport	Experimental group				Control group				Group × time interaction	
	Pre		Post		Pre		Post			
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	$F(1,44)$	η^2
Agility T-test (s)										
RG	14.61	0.67	14.31	0.70	14.52	0.50	14.44	0.50	34.02*	.43
AG	14.64	0.40	14.16#	0.34	14.76	0.47	14.68	0.47		
Jump height (cm)										
RG	19.98	2.01	20.75#	2.30	19.86	0.80	19.87	0.80	25.25*	.36
AG	19.35	1.27	20.50#	1.24	19.57	1.89	19.75	2.52		
Y-Balance Test (% leg length)										
RG	92.85	4.31	96.25	6.80	93.44	5.00	94.17	4.50	28.09*	.39
AG	89.71	6.57	95.52#	8.08	90.44	5.02	91.14	5.51		

Note. RG = rhythmic gymnastics; AG = artistic gymnastics. #statistically significant difference between pre and post values ($p < .05$). *statistically significant effect ($p < .05$)

Results showed that a statistically significant interaction effect was found between group (EG × CG) × time (pre × post) in agility. More specifically, although a non-significant improvement was revealed in both groups on post-measure ($p < .05$), the percentage improvement was higher on EG (2.09% and 3.35% in RG and AG, respectively) compared to CG (0.58% and 0.56% in AG and RG, respectively). This improvement (2.09% and 3.35%) indicates that the PT improved the performance either due to enhanced unit recruitment patterns (Potteiger et al., 1999) or due to neural adaptations (Adams et al., 1992). Furthermore, the improvements in EG were higher than those in CG, suggesting that the training effect is responsible for the CG improvement trend. Moreover, it is inferior to the 4.86% improvement of Miller et al. (2006) who examined untrained adults with the Illinois agility test. Our results align with earlier research by Bogdanis et al. (2019), who discovered that an 8-week supplemental PT program increased CoD and jumping ability in young female gymnasts, reinforcing findings by Miller et al. (2006) who state that a 6-week program significantly improved agility on healthy subjects. The physiological adjustments of neuromuscular function to PT include altered muscle activation methods associated with the SSC and enhanced neural drive to agonist muscles, as shown by Markovic and Mikulic (2010). Agility performance, which represents a wide variety of neuromuscular and locomotor abilities, is greatly influenced by factors including speed, concentric and eccentric muscle contraction, dynamic balance, and whole-body synchronization (Brughelli et al., 2008; Hader et al., 2015; Spiteri et al., 2014). Further, although it seems that the ability to accelerate, decelerate, and CoD is developed at later stages of maturation, our results revealed that agility can be improved following PT in young artistic and rhythmic gymnasts, possibly due to an increase in eccentric strength, which is a major determinant of agility performance (Jones et al., 2009; Spiteri et al., 2014).

A statistically significant interaction effect between group (EG × CG) vs time (pre × post) was observed in relation to the jump height findings. Even though there was no evidence of a group effect, the percentage improvement was higher in EG (3.82% and 5.96% RG and AG, respectively) compared to CG (0.01% and 0.87% in RG and AG, respectively). The study's findings are consistent with other research showing that female athletes from Gymnastics for All (Bogdanis et al., 2019) showed improvements in jumping ability following an 8-week PT. In addition, our results revealed that PT caused an enhancement in squat jump in young gymnasts regardless of the fact that their neuromuscular system has not yet completely matured (Smits-Engelsman et al., 2003) and their elastic tissue is more compliant (Kubo et al., 1999) than the adults. In addition, our results verify previous findings that examined the effect of a 6-week PT and found an increment in jump height of the drop jump in young female rhythmic gymnasts (Nitzsche et al., 2022).

A statistically significant interaction effect was discovered between group × time and the dynamic balance outcomes. More specifically, the percentage improvement on EG was higher in AG (6.47%) and RG (3.95%) compared to CG (0.78% and 0.79%, in AG and RG, respectively). A systematic review revealed no significant improvements in dynamic balance after applying PT (Clemente et al., 2022). More specifically, results showed no significant differences between PT and active controls in dynamic anterior, postero-medial, or postero-lateral balance for both left and right legs ($p > .05$). Additionally, no significant differences were found between PT and active controls in terms of static balance ($p < .05$). However, our results are in agreement with Kanbak and Dağlıoğlu (2020) who revealed benefits of PT in team sports, confirming findings who support that the age of participants may affect the outcome of PT. The relationship between PT and balance has been attributed to the development of neuromuscular adaptability (Asadi & Arazi, 2012). Discrepancies between studies in balance may be attributed to differences in intensity of training, number of contacts, plyometric drills, methods of assessment of dynamic balance, sex, age, and years of experience of the sample population. In general, results revealed that 9–11-year-old female artistic and rhythmic gymnasts may be greatly benefited by PT. In fact, it appears that when traditional gymnastics training is completed with a supervised and well-designed PT protocol it may lead to greater performance gains than gymnastic practice alone in this age group. However, this study has some limitations. Despite the trend of improvement in the examined variables of EG on both sports, the 6-week training period may be considered too short to induce significant differences in these variables in young artistic and rhythmic gymnasts. Therefore, further studies considering longer training interventions are needed to examine longer-term PT in similar populations. It should be noted that during the intervention period, no injuries were observed, and thus, PT may be considered safe for young female gymnasts, under the condition that the difficulty progression guidelines are followed.

Conclusions

A customized 6-week plyometric training program can result in a notable enhancement of performance-related variables associated with artistic and rhythmic gymnasts, including agility, jump height and dynamic balance. These skills which are basic in the exercise program of AG and RG female athletes, must be practiced through special training programs so that a greater percentage of improvement occurs than in the traditional training program applied.

Conflict of interest

The authors report no conflict of interest.

References

Adams, K., O'Shea, J. P., O'Shea, K. L., & Climstein, M. (1992). The effects of six weeks of squat, plyometrics, and squat plyometric training on power production. *Journal of Strength and Conditioning Research, 6*(1), 36–41.

Arazi, H., Asadi, A., & Roohi, S. (2014). Enhancing muscular performance in women: Compound versus complex, traditional resistance and plyometric training alone. *Journal of Musculoskeletal Research, 17*(2), Article 1450007. https://doi.org/10.1142/S0218957714500079

Asadi, A., & Arazi, H. (2012). Effects of high-intensity plyometric training on dynamic balance, agility, vertical jump and sprint performance in young male basketball players. *Journal of Sport and Health Research, 4*(1), 35–44.

Asadi, A., Arazi, H., Ramirez-Campillo, R., Moran, J., & Izquierdo, M. (2017). Influence of maturation stage on agility performance gains after plyometric training: A systematic review and meta-analysis. *Journal of Strength and Conditioning Research, 31*(9), 2609–2617. https://doi.org/10.1519/jsc.0000000000001994

Batista, A., Garganta, R., & Ávila-Carvalho, L. (2017). Strength in young rhythmic gymnasts. *Journal of Human Sport and Exercise, 12*(4), 1162–1175. https://doi.org/10.14198/jhse.2017.124.03

Bogdanis, G. C., Donti, O., Papia, A., Donti, A., Apostolidis, N., & Sands, W. A. (2019). Effect of plyometric training on jumping, sprinting and change of direction speed in child female athletes. *Sports, 7*(5), Article 116. https://doi.org/10.3390/sports7050116

Bosco, C., Luhtanen, P., & Komi, P. V. (1983). A simple method for measurement of mechanical power in jumping. *European Journal of Applied Physiology and Occupation Physiology, 50*(2), 273–282. https://doi.org/10.1007/bf00422166

Bradshaw, E. J., & Le Rossignol, P. (2004). Anthropometric and biomechanical field measures of floor and vault ability in 8 to 14 year old talent-selected gymnasts. *Sports Biomechanics, 3*(2), 249–262. https://doi.org/10.1080/14763140408522844

Brughelli, M., Cronin, J., Levin, G., & Chaouachi, A. (2008). Understanding change of direction ability in sport. *Sports Medicine, 38*(12), 1045–1063. https://doi.org/10.2165/00007256-200838120-00007

Butler, R. J., Lehr, M. E., Fink, M. L., Kiesel, K. B., & Plisky, P. J. (2013). Dynamic balance performance and noncontact lower extremity injury in college football players: An initial study. *Sports Health, 5*(5), 417–422. https://doi.org/10.1177/1941738113498703

Clemente, F. M., Ramirez-Campillo, R., Castillo, D., Raya-González, J., Rico-González, M., Oliveira, R., Rosemann, T., & Knechtle, B. (2022). Effects of plyometric jump training on soccer player's balance: A systematic review and meta-analysis of randomized-controlled trials. *Biology of Sport, 39*(3), 765–778. https://doi.org/10.5114/biolsport.2022.107484

Craig, B. W. (2004). What is the scientific basis of speed and agility? *Strength and Conditioning Journal, 26*(3), 13–14.

Dallas, G., Dallas, C., Pappas, P., & Paradisis, G. (2023). The acute effect of bounced drop jump and counter drop jump with and without additional load on jump performance parameters and reactive strength index on young gymnasts. *Human Movement, 24*(3), 95–105. https://doi.org/10.5114/hm.2023.125931

Dallas, G., Pappas, P., Ntallas, C., & Paradisis, G. (2018). The post-activation effect with two different conditioning stimuli on drop jump performance in pre-adolescent female gymnasts. *Journal of Physical Education and Sport, 18*(4), 2368–2374. https://doi.org/10.7752/jpes.2018.04357

Dallas, G. C., Pappas, P., Ntallas, C. G., Paradisis, G. P., & Exell, T. A. (2020). The effect of four weeks of plyometric training on reactive strength index and leg stiffness is sport dependent. *Journal of Sport Medicine and Physical Fitness, 60*(7), 979–984. https://doi.org/10.23736/s0022-4707.20.10384-0

Daly, R. M., Bass, S. L., & Finch, C. F. (2001). Balancing the risk of injury to gymnasts: How effective are the counter measures? *British Journal of Sport Medicine*, *35*(1), 8–19. https://doi.org/10.1136/bjsm.35.1.8

Faigenbaum, A. D., McFarland, J. E., Keiper, F. B., Tevlin, W., Ratamess, N. A., Kang, J., & Hoffman, J. R. (2007). Effects of a short term plyometric and resistance training program on fitness performance in boys age 12 to 15 years. *Journal of Sports Science and Medicine, 6*(4), 519–525.

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

Granacher, U., Lesinski, M., Büsch, D., Muehlbauer, T., Prieske, O., Puta, C., Gollhoffer, A., & Behm, D. (2016). Effects of resistance training in youth athletes on muscular fitness and athletic performance: A conceptual model for long-term athlete development. *Frontiers in Physiology, 7,* Article 164. https://doi.org/10.3389/fphys.2016.00164

Hader, K., Palazzi, D., & Buchheit, M. (2015). Change of direction speed in soccer: How much braking is enough? *Kinesiology, 47*(1), 67–74. https://hrcak.srce.hr/140253

Jones, P., Bampouras, T. M., & Marrin, K. (2009). An investigation into the physical determinants of change of direction speed. *Journal of Sports Medicine and Physical Fitness, 49*(1), 97–104.

Kanbak, Ç. G., & Dağlıoğlu, O. (2020). Effect of plyometric training program on speed and dynamic balance performances in volleyball players. *European Journal of Physical Education and Sport Science, 6*(9), 138–144. https://oapub.org/edu/index.php/ejep/article/view/3500

Kibele, A., Granacher, U., Muehlbauer, T., & Behm, D. G. (2015). Stable, unstable and metastable states of equilibrium: Definitions and applications to human movement. *Journal of Sports Science and Medicine, 14*(4), 885–887. https://pmc.ncbi.nlm.nih.gov/articles/PMC4657434/

King, J. A., & Cipriani, D. J. (2010). Comparing preseason frontal and sagittal plane plyometric programs on vertical jump height in high-school basketball players. *Journal of Strength and Conditioning Research, 24*(8), 2109–2114. https://doi.org/10.1519/jsc.0b013e3181e347d1

Komi, P. V. (2000). Stretch-shortening cycle: A powerful model to study normal and fatigued muscle. *Journal of Biomechanics, 33*(10), 1197–1206. https://doi.org/10.1016/S0021-9290(00)00064-6

Komi, P. V. (2003). Stretch shortening cycle. In P. V. Komi (Ed.), *Strength and power in sport* (pp. 184–202). Blackwell Science. https://doi.org/10.1002/9780470757215.ch10

Kubo, K., Kawakami, Y., & Fukunaga, T. (1999). Influence of elastic properties of tendon structures on jump performance in humans. *Journal of Applied Physiology, 87*(6), 2090–2096. https://doi.org/10.1152/jappl.1999.87.6.2090

Lindner, K. J., Caine, D. J., & Johns, D. P. (1991). Withdrawal predictors among physical and performance characteristics of female competitive gymnasts. *Journal of Sports Science, 9*(3), 259–272. https://doi.org/10.1080/02640419108729888

Lloyd, R. S., Oliver, J. L., Faigenbaum, A. D., Howard, R., De Ste Croix, M. B., Williams, C. A., Best, T. M., Alvar, B. A., Micheli, L. J., Thomas, D. P., Hatfield, D. L., Cronin, J. B., & Myer, G. D. (2015). Long-term athletic development – Part 1: A pathway for all youth. *Journal of Strength and Conditioning Research, 29*(5), 1439–1450. https://doi.org/10.1519/JSC.0000000000000756

Lloyd, R. S., Oliver, J. L., Hughes, M. G., & Williams, C. A. (2011). The influence of chronological age on periods of accelerated adaptation of stretch-shortening cycle performance in pre and postpubescent boys. *Journal of Strength and Conditioning Research, 25*(7), 1889–1897.

Malina, R. M., Bouchard, C., & Bar-Or, O. (2004). *Growth, maturation, and physical activity* (2nd ed.). Human Kinetics.

Marina, M., & Jemni, M. (2014). Plyometric training performance in elite-oriented prepubertal female gymnasts. *Journal of Strength and Conditioning Research, 28*(4), 1015–1025. https://doi.org/10.1519/jsc.0000000000000247

Markovic, G., Jukic, I., Milanovic, D., & Metikos, D. (2007). Effects of sprint and plyometric training on muscle function and athletic performance. *Journal of Strength and Conditioning Research, 21*(2), 543–549. https://doi.org/10.1519/00124278-200705000-00044

Markovic, G., & Mikulic, P. (2010). Neuromusculoskeletal and performance adaptations to lower-extremity plyometric training. *Sports Medicine, 40,* 859–895. https://doi.org/10.2165/11318370-000000000-00000

Miller, M. G., Herniman, J. J., Ricard, M. D., Cheatham, C. C., & Michael, T. J. (2006). The effects of a 6-week plyometric training program on agility. *Journal of Sports Science and Medicine, 5*(3), 459–465. https://pmc.ncbi.nlm.nih.gov/articles/PMC3842147/

Nitzsche, N., Siebert, T., Schulz, H., & Stutzig, N. (2022). Effect of plyometric training on dynamic leg strength and jumping performance in rhythmic gymnastics: A preliminary study. *Isokinetic and Exercise Science, 30*(1), 79–87. https://doi.org/10.3233/ies-210148

Payne, V. G., & Isaacs, L. D. (2005). *Human motor development. A lifespan approach*. McGraw Hill.

Potteiger, J. A., Lockwood, R. H., Haub, M. D., Dolezal, B. A., Alumzaini, K. S., Schroeder, J. M., & Zebas, C. J. (1999). Muscle power and fiber characteristic following 8 weeks of plyometric training. *Journal of Strength and Conditioning Research, 13*(3), 275–279.

Salonikidis, K., & Zafeiridis, A. (2008). The effects of plyometric, tennis-drills, and combined training on reaction, lateral and linear speed, power, and strength in novice tennis players. *Journal of Strength and Conditioning Research, 22*(1), 182–191. https://doi.org/10.1519/JSC.0b013e31815f57ad

Sheppard, J. M., & Young, W. B. (2006). Agility literature review: Classification, training and testing. *Journal of Sports Science, 24*(9), 919–932. https://doi.org/10.1080/02640410500457109

Smits-Engelsman, B. C. M., Wenstberg, Y., & Duysens, D. J. (2003). Development of isometric force and force control in children. *Cognitive Brain Research, 17*(1), 68–74. https://doi.org/10.1016/S0926-6410(03)00081-8

Spiteri, T., Nimphius, S., Hart, N. H., Specos, C., Sheppard, J. M., & Newton, R. U. (2014). Contribution of strength characteristics to change of direction and agility performance in female basketball athletes. *Journal of Strength and Conditioning Research, 28*(9), 2415–2423. https://doi.org/10.1519/jsc.0000000000000547

Yap, C. W., & Brown, L. E. (2000). Development of speed, agility and quickness for the female soccer athletes. *Strength and Conditioning Journal, 22*(1), 9–12. https://doi.org/10.1519/00126548-200002000-00002