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ARTICLE

A controlled trial of plyometric training for rhythmic female gymnasts.

Fethi Taktak[1], Ines TakTak[2], Roy J. Shephard[3]

Abstract

Background: Plyometrics is a form of training that has proven very effective for many categories of athlete, but there has been little evaluation of this technique in gymnasts. We hypothesized that the performance of well-trained competitive rhythmic gymnasts might be further enhanced by adding a short course of plyometric exercises to their normal regimen. *Methods*: We tested our hypothesis in a sample of twenty female rhythmic gymnasts aged between 17 and 20 years who had no previous experience of plyometrics. Subjects were divided into equal experimental and control groups. The explosive (squat and countermovement jumps with and without arm movement) and reactive (drop jump and stiffness jumps) forces developed by the lower limbs were analyzed using an Opto-jump device before and after the experimental subjects had completed 12 plyometric training sessions over a period of 4 weeks. *Results*: Experimental and control groups were initially well-matched. However, after the 4 weeks of plyometric training, ANOVA showed significant gains in the experimental group on all measures except the Vittori index, with development of a large and statistically significant inter-group advantage to the experimental subjects. *Conclusions*: The data imply that the plyometric programme induced significant improvements in the explosive force, power and relaxation of the quadriceps and triceps surae in those subjects who followed the plyometric regimen. The qualitative balance of strength between the quadriceps and triceps surae was also improved, as was the quality of postural support. We would thus recommend that such a programme be incorporated into the preparation of all competitive gymnasts, as it is in many other forms of sport. **Health & Fitness Journal of Canada 2013;6(3):123-131.**

Keywords: Plyometrics; Vertical jump; High-performance sport; Rhythmic gymnastics

From the [1]Higher Institute of Sport and Physical Education of Ksar Said, Tunis, Tunisia, [2]University "René Descartes" Paris V, France, [3]Faculty of Physical Education & Health, University of Toronto, Ontario, Canada. Correspondence: Rue Tarak Ibn Zied N° 2 SOUSSE 4000 TUNISIA.
E-mail: fethi.taktak@yahoo.fr

Introduction

Plyometrics describes both a form of muscle contraction, and also a specific method of training that seems likely to develop many of the physical attributes that are important in rhythmic gymnastics, such as explosive force, muscle power, triggering movements and relaxation (Zanon, 1974; Cometti, 1987; Carrio, 2001; Challis, 2004). The rhythmic gymnast makes a wide variety of movements, including vertical jumps, and frequent changes of movement, posture and tension. Some of the necessary attributes can be developed simply by practice of the normal gymnastic routines, but plyometric training seems likely to facilitate the progression of athletes who have already developed good qualities of force and speed (Shorten, 1987; Pousson et al., 1988; 1995; Hewett et al., 1996; Young, 2003). Plyometrics enhance proprioceptive skills, psychomotor coordination and vigilance, and through central adaptations, such training can also enhance the gracefulness of motor gestures (Hill, 1970; Huxley, 1974; Lees et al., 2004; 2006). The stretch/shortening cycle associated with plyometric exercise is applicable finds application in many types of body movement (Asmussen and Bonde-Petersen, 1974; Åstrand and Rodahl, 1986), but seems particularly important in rhythmic gymnastics.

This type of training can be adapted to initial ability through an appropriate gradation of the exercises, and it has the advantage of not requiring expensive equipment. Many authors have already highlighted the value of plyometric training in various athletic disciplines. Bosco et al. (1983), Brown et al. (1986) and Church et al. (2001) have all shown that counter-movement jumping exercises can increase the vertical jump height of competitors. The consensus among these authors is that some 57% of the improvement in score reflects an enhanced jumping ability, and 43% is due to gains of muscle strength. According to Ridderikoff et al. (1999) and Wisloff et al. (2004), plyometric training also increases leg-arm coordination. Harman et al. (1990), Bobbert et al. (1996), Chu (1998), Matavulj et al. (2001) and Bouhlel et al. (2006) have all explained the gains in counter-movement jump scores following drop jump training as arising from a combination of increased hip extensor strength, a greater speed in the development of explosive force, and greater relaxation. On the other hand, the height from which counter movement jumps are made during plyometric training does not seem to affect gains in score (Kokkonen et al., 1998; Knudson et al., 2001; Jaris et al., 2002).

The choreography of rhythmic gymnastics is becoming ever more diverse, and typical programs include many jumps. It is important to maximize jump height, thus allowing the gymnast to remain air born for sufficient time to complete the intended routine. An increase in vertical jump height improves the aesthetics and the precision of many movements (Siskova, 1982). Fahey et al. (2000) recommended that gymnasts should adopt plyometric training some 12 years ago, but there remains a dearth of objective data in this particular athletic discipline. How effective is plyometrics in improving the specific physical abilities of rhythmic gymnasts who have already reached a plateau in their response to other forms of training? To what extent can the introduction of a short period of plyometric training make quantitative improvements in the performance of such individuals? Top-level gymnasts in Tunisia have not previously adopted a plyometric regimen, allowing us to test how far the addition of a short period of such training yields quantitative improvements in the vertical jumping ability of otherwise well-trained and experienced gymnasts, and to see how far such a regimen corrects imbalances and weaknesses in their performance.

Methods

Participants

All procedures were approved by the Institutional Review Committee for the ethical use of human subjects of the Higher Institute of Sport and Physical Education of Ksar Said, Tunis, according to current national and international laws and regulations. Participants gave their written informed consent after receiving both a verbal and a written explanation of the experimental protocol and its potential risks. Subjects were told that they could withdraw from the trial without penalty at any time. The sample comprised 20 female gymnasts from the Tunisian national team, aged 17 to 20 years. Their mean gymnastic experience was 11 ± 14 years. None had previous experience of plyometric training. They were examined by the team physician, with a particular focus on conditions that might preclude plyometric activities, and all were found to be in good health. Subjects were divided arbitrarily into two groups of 10: an experimental group (aged 18.2 ± 2.1 years, height: 1.75 ± 0.03 m, body mass 55.1 ± 2.7 kg) and a well-matched control group (aged 18.4 ± 2.6 years, height: 1.75± 0.03 m, body mass: 54.7 ± 2.3 kg).

Training programme

The normal training program involved six 2-hour rhythmic gymnastics sessions per week, devoted largely to the practice of intended choreographic routines. The experimental group supplemented this standard regimen by three weekly 40-55 min sessions of plyometric training for each of 4 weeks. During this period, the control group followed their regular training programme.

Table 1: Programme of plyometric exercises.

Simple plyometric exercises included activities with low boxes, leaping through hoops, and skipping over mats, with 1 to 3 minute recovery intervals between sets.
Average plyometric exercises included jumping through hoops (with differing angles of flexion), rope jumping, and jumping over benches, again with a recovery period of 1 to 3 minutes between sets.
Intensive plyometric exercises included side-jumps over benches (making a rebound on the bench), the use of high plinths and countermovement jumps. For these exercises, recovery periods of 3 to 5 minutes per set were allowed.

Individual plyometric training sessions began with a carefully planned 15 min warm-up. This was followed by 25-35 min of plyometrics (Table 1). The duration was 35 min when simple plyometric exercises were scheduled (Sessions 1 and 12), 30 min when average plyometric exercises were undertaken (Sessions 2, 4, 5, 7, 8, and 10), and 25 min if intensive plyometric exercises were performed (Sessions 3, 6, 9 and 11). All plyometric sessions emphasized bounding exercises to strengthen muscles of the lower limbs, especially the quadriceps and triceps surae. The intensity of training increased, then decreased, and then increased again, reaching its maximal intensity during the final sessions. In periods when the intensity was decreasing, the volume of work was increased, and vice-versa. The necessary equipment was quite simple: skipping ropes, hoops (spaced 1 meter or 1.5 meter apart for horizontal leaps), mats for vertical leaps, 0.3 m high Swedish benches, a stopwatch to regulate the recovery time and the Opto-jump optical measurement system (Microgate, Bolzano, Italy) to assess flight-time derived jump heights and contact times and thus assess power and relaxation to 1 msec; such data correlate closely with force-plate estimates (Glatthorn et al., 2011).

Evaluations

The measures used in evaluating the subjects before and after plyometric training (Table 2) were completed in a fixed order over 2 consecutive days. The final tests were conducted 5 to 9 days after the last plyometric session, in order to ensure adequate recovery from the acute effects of training. Two tests with verbal encouragement were allowed for each measurement, and the best of the two scores was recorded. Jumps were made as vertically as possible (checking that the gymnasts landed at their starting position).

Table 2: Evaluation methods.

Squat jump (SJ). A single jump was made from a squatting position (Asmussen and Bonde-Petersen, 1974; Chelly et al., 2010). At the first signal, the subject placed her hands on her hips, and bent the knees to 90° without leaning forward, and at the second signal, she pushed upwards, jumping as high as possible. The SJ assesses a combination of muscle force and "inelastic" relaxation.
Counter-movement jump (CMJ). A single jump was made from the erect position (Asmussen and Bonde-Petersen,1974; Chelly et al., 2010). At the first signal, the subject stood with her hands on her hips, making a flexion-extension movement of the lower limbs; after landing on the ground, she made a rebound jump as high as possible. The CMJ allows the subject more time to develop force than the SJ. The scores obtained are thus closer to the individual's maximal force.
Free arm counter-movement jump (CMJ-fa). A single jump was made from the erect position, with the arms hanging freely, and allowing a counter-movement (Bosco, 1985). The CMJ-fa reflects the resultant of muscle power and arm-leg coordination.
Drop jump (DJ). A single jump was made from a height of 0.3m (Asmussen and Bonde-Petersen,1974; Markovic et al., 2007). The subject maintained an erect position, with the arms hanging freely and making a counter-movement. She was asked to place one foot to the front, and then to drop and to jump as high as possible (with 90° flexion).
Stiffness jumps. Six jumps were made from an erect position, with the arms hanging freely and the knees locked (Dalleau et al., 2004; McMahon et al., 1990). The Opto-jump equipment allowed measurement of the average height of the 6 jumps and the average power developed. The first jump was like a CMJ; the gymnast was then required to jump as high as possible for the remaining 5 jumps, with the help of arm movements. This test assessed the individual's quality of bounce and the strength of her calf muscles.
Jump height index. The algebraic sum of SJ, CMJ-fa and stiffness jump scores.
Thigh power index. Calculated as (CMJ - SJ)
Vittori index (Bosco et al., 1995). Calculated as the average height of the 6 stiffness jumps, divided by CMJ-fa. The optimal ratio lies between 0.9 and 1.1.

Statistical procedures

All data were normally distributed. Values were expressed as mean ± standard deviation, using the SPSS 13.0 program. ANOVA allowed intra- and inter-group comparisons over the 4 weeks of training. The significance level was set at $P < 0.05$.

Results

All scores for the control group remained very stable over the 4-week period of observation (Table 3). However, the experimental group showed a substantial and highly significant increase in all scores except the Vittori index following plyometric training.

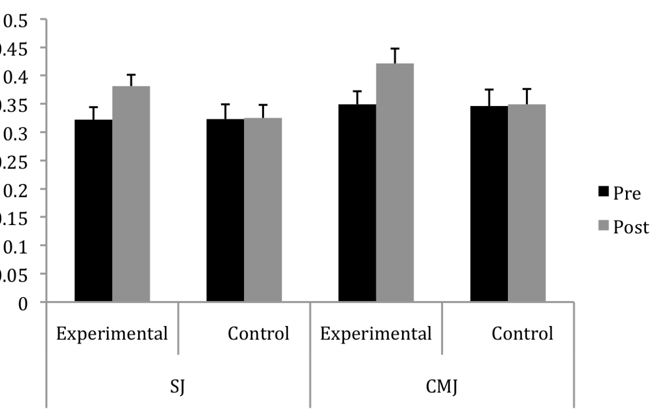
In terms of the standing jump, ANOVA confirmed the effectiveness of plyometric training in improving upon the standard regimen. Intra-group comparisons showed a significant increase of score in the experimental group ($p < 0.0001$), with a highly significant inter-group difference in response ($p < 0.0001$) (Figure 1). ANOVA data for the CMJ, the CMJ-fa, and the drop jump showed similar patterns, with highly significant improvements of performance in the experimental group ($p < 0.0001$), and inter-group comparisons demonstrating a highly significant advantage of final score to the experimental group ($p < 0.0001$)(Figure 2).

There were significant improvements ($p < 0.0001$) of score for the 6 "stiffness" jumps, the relaxation index (SJ + CMJ-fa + stiffness score) and the index of thigh power (CMJ-SJ) in the experimental group ($p < 0.0001$), with a clear final difference between their scores and those of the control subjects ($p < 0.0001$).

Table 3: Scores for experimental and control groups, before and after experimental group received 4 weeks of plyometric training (Mean ± SD).

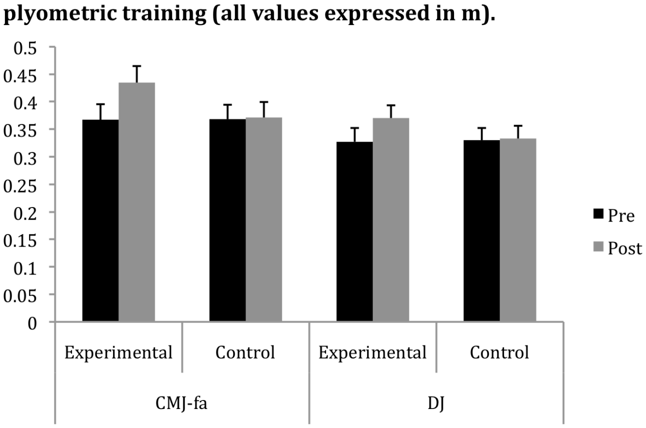
Variable	Experimental group		Control Group	
	Before	After	Before	After
Squat jump (m)	0.32 ± 0.02	0.38 ±0.02**	0.32 ±0.03	0.33 ± 0.02
CMJ (m)	0.35 ± 0.02	0.42 ± 0.03**	0.35 ± 0.03	0.35 ± 0.03
CMJ – free arms (m)	0.37 ± 0.03	0.44 ± 0.03**	0.37 ± 0.03	0.37 ± 0.03
Drop jump (m)	0.33 ± 0.03	0.37 ± 0.02**	0.33 ± 0.02	0.33 ± 0.02
Stiffness jump score (m)	0.30 ± 0.02	0.38 ± 0.02**	0.30 ± 0.02	0.31 ± 0.02
Jump height Index	99.0 ± 4.2	119.1 ± 4.4**	98.9 ± 3.6	100.4 ± 4.1
Thigh Power Index	2.7 ± 3.0	4.0 ± 3.2*	2.3 ± 4.0	2.5 ± 3.3
Vittori Index	0.8 ± 0.1	0.9 ± 0.1	0.8 ± 0.1	0.83±0.09
Significant differences from initial data: * p < 0.05 ; ** p < 0.0001 CMJ = counter-movement jump				

Figure 1: Scores for squat jump and countermovement jump before and after experimental group received 4 weeks of plyometric training for (all values expressed in m).



Note: Experimental group shows significant differences between values measured before and after plyometric training (p<0.0001).

Figure 2: Scores for the countermovement jump with free arms (CMJ-fa) and for the drop jump (DJ) before and after experimental group received 4 weeks of plyometric training (all values expressed in m).



Note: Experimental group shows significant differences between values measured before and after plyometric training (p < 0.0001)

Discussion

Our team of gymnasts were already well-trained, experienced and competing at an international level, yet our results showed that surprisingly large gains of jumping ability could be induced with quite a limited volume of supplementary plyometric exercise (a total of only six hours, spread over 12 sessions during a 4 week period). Several explanations can be made for this finding. Much of the progress of the experimental group could reflect a greater ability to relax, a skill which was not well developed through their standard training program, but which is enhanced by plyometrics (Pousson et al., 1995). The effective muscle strength of the experimental subjects was also enhanced because of increased involvement of the stretch-shortening cycle (thus reducing the energy cost of their movements, Paavolainen et al., 1999). Optimization of the stretch-shortening cycle was particularly marked in the CMJ, with the experimental subjects developing both a greater efficiency in their storage and subsequent release of elastic energy, and a better inter-segmental coordination. Moreover, as previously reported by Wilson et al. (1996), plyometric training enhanced maximum concentric power, as shown by increased squat jump scores.

The ability of an athlete to develop force depends on three main factors (Chimera et al., 2004; Fukunaga, 1976):

1. Structural factors: the number, size and composition of the muscle fibres;
2. Neural factors: the ability to coordinate the activation of motor units, and
3. Stretch-related factors: the ability to potentiate the muscular contraction.

Plyometric activity can (1) increase maximal voluntary force (Matavuli et al., 2001); (2) reduce inhibition of the myotatic reflex (Schmidbleicher, 1988); (3) raise the threshold of the Golgi receptors (Bosco, 1985); (4) enhance the sensitivity of the muscle spindle (Pousson, 1988); (5) reduce the coupling time (Bosco, 1985); and (6) increase muscle stiffness (Pousson, 1988). The ability to withstand a heavy load during the stretch phase of the stretch-shortening cycle is also improved. In our study, the experimental group showed significantly improved scores for the SJ, CMJ and CMJ-fa. Plyometric training perfects use of the arms in jumping, and this undoubtedly made an important contribution to enhanced performance of the CMJ-fa. The gains in SJ were of similar magnitude to those for the CMJ, so that CMJ-SJ (the index of thigh power) showed little change. The experimental group made a large number of downward jumps during training, and this offers at least a partial explanation of the significant improvement in drop jump scores; it is also possible that gymnasts underwent a progressive neural adaptation to this type of jump, which involves muscle contraction and a simultaneous activation of the myotatic reflex (Bosco, 1985). The ability to store and release more energy probably accounts for the enhanced response to the 6-jump "stiffness" test.

The relaxation index changed very significantly in the experimental group, due to significant increases in the power of the thighs (CMJ), explosive power (SJ) and the power of the triceps surae (the “stiffness” test). The power of the thighs also showed a significant improvement.

The initial performance of the control group closely matched that of the experimental subjects, but they showed no significant change in any of their test results over the trial. This clearly confirms that the gains seen in the experimental group were a consequence of the added plyometric training rather than some seasonal effect. Many previous authors have underlined the benefits of plyometrics, including an increase in the maximal force realized during explosive movements, greater relaxation, and a decrease in inhibition of the myotatic reflex, all factors that a simple activity analysis suggests are of importance to the gymnast. However, there has been little scientific study of the role of plyometrics in the preparation of rhythmic gymnasts. In keeping with our observations, Hutchinson et al.1998) noted that after one month of plyometric training, gymnasts improved their explosive power by 220%, their ground reaction time by 50%, and the height of their leaps by 16.2%. The present study further underlines the value of a brief period of plyometrics in improving the physical capabilities of gymnasts. We observed very significant gains, both qualitative (the quality of support and the balance of the lower limbs) and quantitative (improvement of performance in the various jumps). Nevertheless, further study is needed to see how long the gains that were observed in the experimental group persist, and whether the improvements in performance in the laboratory translate into better scores during gymnastic competition.

Finally we would emphasize certain limitations of our study. The sample was small, and was limited to young female gymnasts at one level of competition. Observations should be repeated on a larger and more diverse group of subjects in order to test the generality of our results to various ages, both sexes and various initial levels of training. It would also be interesting to compare the effectiveness of plyometric regimens that differ in the number, duration and scheduling of training sessions. Finally, although quantitative improvements in jumping ability were demonstrated, it remains important to examine the impact of such gains upon the qualitative performance of gymnasts.

Conclusions

A brief plyometric training programme (12 sessions over 4 weeks) was sufficient to induce significant improvements in the explosive force, power and relaxation of the quadriceps and triceps surae muscles in gymnasts who had been following a programme that focussed on practice of their skills. The qualitative balance of strength between the quadriceps and triceps surae was improved, as was postural support. We would thus recommend that such a programme be incorporated into the preparation of competitive gymnasts, as it is in many other forms of sport.

Authors' Qualifications

The authors' qualifications are: Fethi Taktak S.D.; Ph. D.; Inez Taktak Ph. D student; Roy J. Shephard M.B.B.S.; M.D. [Lond.]; Ph. D.; D.P.E.; LL.D.

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