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ORIGINAL ARTICLE

Plyometric Training Effect on Lower Limb Biomechanical Parameters

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ABSTRACT

Plyometric training can be reduced of injury potential and increase of athletes' motivation for participates in sport training. Those, the aim of this study was survey the effect of plyometric and whole body vibration combined training on lower limb biomechanical parameters in nonathletic male students. For this purpose, 40 Physical male students who were similar in terms of practical courses in Islamic Azad University of Karaj voluntarily chosen and in four categories: (1. Plyometric, 2. Vibration, 3. Combination and 4. Controls) were studied. Isokinetic Biodex system was used to assessment of lower extremity biomechanical variables before and after training period. The training period was six-week that at this time plyometric and vibration group run the selection of the mentioned training and combined group in each training session run plyometric as well as vibration training alternatively. After reviewing the data distribution normality with Kolmogorov - Smirnov and Levine test to homogenize variances, to describe the demographic characteristics of the subjects were tested using descriptive statistics. Data were analyzed using ANOVA with repeated measures (4 × 2), One-way ANOVA, t-test and Scheffe's post hoc in 16 version of SPSS software. Results showed that the effects of a plyometric, vibration and combination training of biomechanical variables of knee extensors and ankle plantar flexors were significant. But the effects of combined training in almost were higher all measured variables in this study. Combined training reduced the recovery time and easier the super compensation than plyometric training. It can be suggested that for optimum results, particularly in the explosive sports, combined training (plyometric and Vibration) is used.

Keywords: Lower extremity, vertical jump, plyometric training

INTRODUCTION

In general, the gravity causes most of the mechanical motions that are responsible for the development of the muscular structures. On the other hand, the specific programs of strength training and explosive power exercises, involve the gravitational acceleration change rate and amount. This would cause more stimulation from the gravity in order to enhance the physical fitness factors (Darryl, 2004). Also, gravitational changes can be caused by the mechanical devices and motors like whole body vibration platform known as WBVT (Darryl, 2004). This means that by using WBVT, one can experience more stimulations and motions compared to the normal daily activities (Darryl, 2004). Vibration, as a factor causing strong mechanical stimulations in neuromuscular system, skeletal tissues, and muscles, have been widely studied in medicine, ergonomics and animal experiments (Cardinal, 2010). Nowadays, the application of WBVT as a rather novel method for neuromuscular training is a hot topic (Cardinal, 2010). Moreover, WBVT method is used as a positive method for increasing the muscular strength, the body balance, the mechanical capacity of the bones, and the bones' mineral density (Delecluse, 2009).

The importance of the strength and power trainings, as common features of many sport activities, has been

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confirmed by many studies which demonstrated that working with weights and more recently plyometric exercises, enhance the performance in competitions (Earl, 2001). The coaches and athletes claim that the plyometric exercises, bridges the gap between the power and strength and directly enhances the performance. They often regard the power work-outs as sources that increase the general power and they also consider the plyometric training as a method for applying this power (the general power increased by power training) in order to enhance the performance of the athletes (Ferris ,2001). The plyometric exercises are designed in order to reach the maximum power and especially the maximum explosive power in the least possible time, which takes place by decreasing the amortization phase (Stane, 2005). Nevertheless, conducting plyometric exercises because of its consecutive jumps and hops, can exhaust the athlete and increase the injury possibility; therefore many experts in the training field, suggest that for reaching the proper training results, besides the plyometric training, another training method be used for preparing the athletes.

the many reasons preventing the athletes of certain sport fields, reaching the maximum capacity in the vertical jumps, one can mention the disregard to the effective issues on the vertical jump, or paying too attention to certain aspects of skills. Being unaware of the correct techniques of jumping, doing improper exercise movements for reinforcing the muscles involved in the jump, or using routine , repetitive and exhausting training methods in a certain sport field, are the causes which bring about severe consequences such as exercise-induced nausea, shortened championship period, frequent injuries , and athlete's failure in various competition levels. Considering the role of the joints and the various biomechanical parameters in optimum performance of various kinds of jumps, many studies have been conducted in order to detect the effective parameters like peak torque (PT) from different perspectives and aspects. For instance, Dowling and Vamoose (2008) in a research conducted using force plate, reported that the PT parameter can be used as an excellent predictor for the height of the vertical jump , in the lower limb joints (Dowling , 2008). In another research, Wiklander and Lysholim (2009), investigated the significant relationship between the PT of the knee extensor muscle joint in the speed of 180 degree per second , and the height of the vertical jump (Wiklander, 2009). Also, in some other studies, the relationship among the joints and other biomechanical factors such as AT, ROPTD, AP, ATPT were discussed considering the jump action and the sport performance of the athletes that confirmed the significant relationship between the aforementioned factors and the sport performance. Studying the effect of various exercises on the factors underlying the vertical jump performance, besides offering us a more comprehensive knowledge about the mechanism of performing such a skill, can effectively contribute to the modification and reconstruction of the previous training methods or it can lead to novel exercise methods design , which in turn can help us in designing the training programs, especially the ones which are conducted in the phase of converting the general strength into strength in speed or power. A general review of the related literature, indicates that there has been no study dealing with the effect of plyometric exercises and vibration on the mechanics of the lower limb. In addition, despite the fact that in the previous studies, the significant effect of the plyometric trainings on the explosive activities were confirmed, it should be noted that the effect of the plyometric exercises has not been studied in detail, on the biomechanical parameters affecting the power activities performance, and also the effect of the combining the plyometric exercises with vibration trainings has not been considered in the literature. Combining the plyometric exercises with other training methods, can bring about many advantages for the athletes. Of the many positive consequences, one can point to the injury possibility reduction, which is one of the likely results of doing plyometric trainings due to the long period of jumping and landing, and also observing the variety in training in order to prevent the exercise-induced nausea. Therefore, the purpose of the present study is to investigate the combinational effect of the plyometric exercises and full-body vibration on a selected biomechanical variables of the lower limb in male non-athlete students.

MATERIALS AND METHODS

Subject Selection

This research includes in the pretest and posttest studies, three experimental groups and one control group.

Forty male students of Physical Education, having similar applied syllabuses in the course of the semester, were voluntarily selected from Karaj Islamic Azad University. The subjects answered a structured questionnaire about their health. Subjects having injury records in the lower limb and also the ones who had had nervous injuries and problems, were removed from the research.

Experiment Conduct Method

The subjects selected for participating the research, gathered in the physiology laboratory of Kharazami University of Tehran, one day before doing the exercises ,so that their heights, weights and BMI values (weight in kilograms (kg) divided by height in meters, squared (m2)(. Then, the stronger foot of each of the subjects was determined by using this particular data that by which lower limb, the subject is willing to kick the soccer ball. Afterwards, the style of administering the test was explained by the tester to the participants. Then, the subjects did a 5-minute warm-up phase (slow running), and after that, they stretched the hamstring muscles, the quadriceps, the sciatic muscles, the inferior gemellus muscle , the soleus muscle , the thigh flexors and the IT band for five minutes. After the warm-up, the maximum power of the subjects for the knee extensor muscle, was recorded by a Biodex machine. Then, the subjects were ranked according to the isometric power of the knee extensor muscles, and were put in three experimental groups and one control group. After putting the subjects in special groups, the pretest data as explained before was recorded with a 24-hour rest. The next day, the subjects of each group, started the trainings related to their groups, in the laboratory of Karaj Kharazmi University.

Measuring the Isometric Power of the Knee Extensors

The American 3-Model Isokinetic Biodex Machine was the instrument for measuring the maximum isometric power of the knee extensors. According to the manual of the device, the dynamometer of the machine was registered in 90-degree angle. The posterior slope angle of the chair was considered 85 to 90 degrees. Special tapes were used for fixating the thigh and the upper limb, so that only the thigh extensors muscles' power be recorded. On the basis of the previous studies findings, the maximum power of the knee extensors were registered in 30-degree angle. The reason lies in the fact that in this angle, the least changes of the maximum isometric power has been recorded for the knee extensor muscles. In order to record the data according to the maximum produced torque per Newton-meter, each subject made three 5-second attempts, had a 5-second rest in the intervals. The mode of the isometric and concentric machines were taken into consideration.

Measuring the Biomechanical Parameters of the Knee Extensors Muscles

The biomechanical parameters of the lower limb in the knee and stronger ankle joints was measured by the isokinetic machine in the angular speed of 180 degrees per second. In order to measure the biomechanical parameters of the knee extensors, each subject would get on the special seat of the Biodex machine, and his leg would be fixated by the special tapes from above the given joint, in such a way that during the movements and training, the activator muscles in the other joints would not be used. It should be remarked that the subject's position on the seat was in a manner that the angle of the body was 90 degrees in flexion status, and the ankle was free. The height of the seat was adjusted in such a way that the center of the knee joint (the external epicondyle of the femur) was situated opposite the dynamometer's rotation axis. For registering the isokinetic parameters of the knee, the knee special connection was used. The connection padding was installed 5 centimeters higher than the external ankle. Then, the subjects were asked to extend their knees with the maximum power on the Biodex machine, three times with an angular speed of 180 degrees per second. The measured biomechanical parameters (PT, the time of reaching the PT, the angle reaching the PT, the time of acceleration, and the average power) were recorded by the machine. The Biodex machine, among each subject's repetitive attempts, selected the one with the maximum amount of PT and presented all the other desired parameters in that repetition, as the output. In case of having the recorded coefficient of changes (uniformity coefficient of the repetitions) lower than 15, the measured parameters were regarded as valid enough. In the present study, the isokinetic parameters of the concentric contraction were recorded.

Measuring the Biomechanical Parameters of the Ankle Plantar Flexors

For measuring the biomechanical parameters of the ankle joint plantar flexors, the subject in a manner similar to the previous status (the position for measuring the knee extensors parameters) took the seat and his knees were in 20 to 30 degree flexion state. Then, he would do the plantar flexion for three times with an angular speed of 180 degrees per second, with the utmost power. The measured biomechanical parameters (PT, the time of reaching the PT, the angle reaching the PT, the time of acceleration, and the average power) were recorded by the machine, during the ankle plantar flexion. The height and the angle of the seat, and also the direction and the angle of the dynamometer, were adjusted in a way that the external ankle would be placed facing the dynamometer rotation axis. The dynamometer angle was adjusted 90 degrees and its tilt amount was set in 50 degrees.

The resulting information (the Biodex output), was used in both cases measuring the knee extensors and ankle plantar flexors, in calculating the parameter of the peak torque development rate. The peak torque development rate is calculated by dividing the PT by the parameter of time of reaching the PT.

Plyometric Training Course

The subjects of the plyometric training group did a variety of plyometric exercises, designed for the lower limb, in a 6-week training program. This training protocol consisted of three and four sessions of exercises in a week, in every other manner, with a training capacity of 90 to 110 foot-contacts in every session. The training plan included five plyometric movements, that the subjects would do each movement for 60 seconds. These movements were: 1.double-leg forward jump over the hurdles, 2. Double-leg lateral jump over the hurdles using the stronger foot, 3. Single-leg forward jump over the hurdles using the stronger foot, 4. Single-leg lateral jump over the hurdles using the stronger foot, and 5. Double-leg forward and backward zigzag jump. As usual, between each action, a 60-second rest interval was observed. The subjects in each training session, after doing all the five movements, accomplished the next round, in the same manner with the first one, and by completing the second round , the trainings ended (Yen , 2010). The timing of the plyometric training plan was exactly in line with the vibration training group plan.

Statistical Analysis

In order to verify the normality of the data distribution, Kolmogorov-Smirnov test; for unifying the variances of the observed groups, Leven's test; and for describing the individual characteristics of the subjects in each four group, the descriptive statistics were used. The analysis of the collected data in the pretest and posttest stages in different groups was done by the use of combined variance analysis test (2×4), one-way variance analysis, t-test for the dependent groups and the Scheffé's post-hoc test in the significance level of 0.05, and it was executed in the interface of SPSS Software version 16.

RESULTS

Three descriptive statistical data is shown in Table 1, belonging to the individual characteristics of the research participants, separately for each group.

The results showed that after finishing the plyometric , vibration and compound trainings , the time of reaching to PT , PT ,the average power , the acceleration time, and PT development amount related to knee extensors , and the same parameters related to ankle plantar flexors , enhanced. However, the angle of getting the peak torques of knee extensors and ankle plantar flexors, and also the

Table 1. The mean and standard deviation of the individual characteristics of the subjects distinguished by groups

Variable / Group	Age (year)	Weight (kg)	Height(cm)	Body Mass Index
Plyometric	23.46 ± 2.61	71.39 ± 4.68	176.42 ± 7.41	32.10 ± 3.69
Control	22.12 ± 1.86	70.87± 5.12	175.53 ± 6.25	22.87 ± 3.59

Table 2. Isokinetic Parameters of the Lower Limb, Before and After the Plyometric Training in Knee and Ankle Joints

Joint / Parameter	Knee Joint		t	P	Ankle Joint		t	P
	Pretest	Posttest			Pretest	Posttest		
TTPT	181.2 ± 12.3	142.6± 6.32	8.676	0.021	152.23±16.3	144.6±12.6	1.676	0.063
PT	121.4 ± 8.5	162.3 ± 7.26*	9.43	0.002	53.34±5.7	68.3±7.26*	10.46	0.001
ATPT	109.18±9.7	111.2±11.32	0.893	0.214	34.18±4.6	33.2±4.74	0.089	0.13
AP	191.2±12.6	240.7±11.3*	7.54	0.018	73.36±6.5	91.6±5.3*	11.36	0.013
AT	58.44±8.3	45.7±11.3	9.34	0.007	79.18±5.3	76.2±7.83	1.32	0.09
ROPTD	1.23±0.07	2.14±0.13*	9.35	0.023	1.08±0.01	1.08±0.021	1.51	0.17

TTPT= Time to Peak Torque
PT= Peak Torque
ATPT= Angle to Peak Torque
AT= Acceleration Time
ROPTD= Rate of Peak Torque Development

acceleration time and the ankle plantar flexor development amount, after completing the trainings, did not show any significant changes.

Plyometric Trainings

Plyometric trainings caused a reduction in the time of reaching the PT and also the acceleration time of the knee extensors. Moreover, executing the plyometric training protocol for 6 weeks significantly increased the knee extensors PT, average power, PT development amount, and the ankle plantar flexors PT and average power (Table 2).

Comparison

According to the percentage of changes, the compound training group had almost experienced the most changes. Also , in case of the variable peak torque of the ankle plantar flexor muscles , the compound training had more effect compared to the plyometric and vibration trainings. The variable of the time of reaching the peak torque of the ankle plantar flexor, showed a significant reduction only after executing the compound trainings. The execution of compound training similar to the plyometric training, compared to the vibration training, had more impact on the explosive power of the lower limb, the peak torque development amount , the average power , and the time of reaching the peak torque of the knee extensors.

On the basis of the mean percentage changes, almost in all the studied factors, the execution of vibration training had less effect compared to the plyometric and compound training. However, the effect of this training method on the average power of the ankle plantar flexors was almost close to the effect of the plyometric and compound trainings. Also, the effect of vibration training on the peak torque of the plantar flexors did not show any significant difference compared to the plyometric trainings.

DISCUSSION

The purpose of this study is to define the effect of combined execution of plyometric and whole body vibration trainings on a set of selected biomechanical variables of the lower limb in the male non-athlete students. In general, the results showed that after executing the plyometric, vibration and compound training methods , the time of reaching to PT , PT ,the average power, the acceleration time, and PT development amount related to knee extensors, and the same parameters related to ankle plantar flexors, enhanced. However, the angle of getting the peak torques of knee extensors and ankle plantar flexors, and also the acceleration time and the ankle plantar flexor development amount, after completing the trainings, did not show any significant changes. Also, the results showed that after doing the trainings, of all the measured biomechanical parameters, the effect of the compound trainings was significantly higher.

In the previous studies in the field, it is proved and confirmed that executing plyometric trainings, increases the power. Hewett et al (1999) reported an increase in the isokinetic power of the quadriceps and hamstring muscles and also an enhancement in the power ratio of the hamstring to the quadriceps in female trained athletes affected by plyometric exercises (Hewett et al, 1999). Influenced by the power increase caused by the plyometric trainings, the voluntary individual effort for producing force increases that considering the recruitment of bigger motional units with bigger cell germ and thicker axon , one can expect that the produced torque of the muscular group undergoing plyometric training increase. In sum, it can be said that executing plyometric training, besides increasing the muscular power, especially in quadriceps, increases the neurotic conduct speed and consequently the contraction speed, and apart from increasing the average power and the peak torque, it would bring about the increase in the knee extensors peak torque development amount, and the ankle plantar flexors' average power and peak torque.

Of the other possible reasons by which, the effect of the plyometric training on the factors of vertical jump can be justified, one can refer to the neuromuscular harmony improvement and the effective changes taken place in the activities of muscular spindles and Golgi tendon organ. The previous studies, have confirmed the increases of the activities of the muscular spindles, and the decrease of the activities of the Golgi tendon receptors after doing the plyometric trainings (Hewett, 1999, Jeffrey, 2001). The results of the research showed that in spite of the significant reduction in the time of reaching the peak torque and the knee extensors muscles' acceleration time, it was also observed that the aforementioned factors in ankle plantar flexors had not experienced any significant change. The previous studies did not report any significant relationship between the acceleration time of the ankle plantar flexors with the vertical jump; however the knee extensors' acceleration time has rather important relationship with the vertical jump execution (0.46). Also, the relationship between the peak torque reaching time in knee extensors muscles and vertical jump is more significant compared to the relationship of ankle plantar flexors and vertical jump (0.37 against 0.09). Each plyometric training session consists of several kinds of single-leg or double-leg jumps, so it is probable that the parameter whose relationship with the vertical jump is almost zero (at the time of acceleration time) or very low (the time of reaching the peak torque), after completing these trainings, would not experience any significant changes.

Executing vibration trainings for 6 weeks significantly increased the knee extensors PT, average power, PT development amount, and the ankle plantar flexors PT and average power. Also, doing this training method, reduced the time of reaching to PT of the knee extensor muscles. In any case, applying the vibration exercises as a training method for improving the sport performances has become very popular in the recent years , and from 1998 to 2008 , more than 15 studies , have confirmed the positive impact of such training method in improving athletic performances (Punakallio, 2005). Presenting definite theories on using the method with a training protocol or certain intensity , is very difficult and needs further studies whose results requires careful analysis and discussion.

The results of the present study is compatible with the study results of Reyes et al (2008) and Bogaerts et al (2007), that had reported the sport performance enhancement, and also the concentric and eccentric power of the knee extensor muscles after the execution of vibration trainings. In addition , the results of this study about improving the vertical jump execution are in line with the results of Marco Cardinal's (2002) study, in which, after 10 days , the vertical jump of the experimental group had improved 11.9 percent, and also with the results of Bosco et al (2000) , that showed a 5-percent improvement of the power after the vertical jump test (Reyes, 2008; Bogarts, 2007; Marco Cardinale, 2002; Bosco, 2000). However, the results of this study are not compatible with study results of Yosuku Osawa et al (2011), Artero et al (2011), Javier et al (2010) and Stifansen (2005), that reported no significant changes in isometric and isokinetic power of the knee extensor muscles , no improvement in the performance and no increase in explosive power and the vertical jump height after the vibration training (Osawa , 2011 ; Artero , 2011 ; Javier , 2010 & Stefanson , 2005).

The possibility that the results of the present study are compatible or incompatible with the results of the other studies, is due to the similarity of the training variables to the compatible studies results and the difference of the training variables with the incompatible studies. In an investigation done, most of the studies reporting the effects of vibration training on sport performances, used frequencies between 25 to 30 Hz, and domains 10 mm or less. The training variables of the frequency and the domain of the present study, are equal or very close to the compatible studies, especially the frequency was almost the same in all the studies. Since Bosco calls frequency as the most important training variable leading to vibration effects, so possibly one of the main reasons why our results are compatible with the other studies results, is the similarity of the aforementioned variable, which is the frequency (Torovinen, 2002).

In any case, executing the compound training did not have significant effect on the reaching the peak torque angle of the knee extensors and the acceleration time , peak torque development amount and the peak torque reaching angle of the ankle plantar flexors. On the basis of the previous studies' results the angle of reaching the peak torque has significant relationship with the maximum torque creation angle in each joint. Also, the studies showed that although the produced torque shows significant changes in angles 60 and 90 degrees of the knee extensors, and angles 30 and 60 degrees of the hamstring muscles, the angle of maximum torque creation of the muscles after the training round, would not give a significant difference. Therefore, it is probable that by applying the plyometric, vibration and compound trainings, despite the increase in isometric power and the muscles produced torque and strength, no significant changes take place in the maximum torque.

CONCLUSION

The results generally showed that after a round of plyometric training the biomechanical factors underlying the jump action, increase. Considering the findings of the present research, the execution of the plyometric training in power fields, is preferred to the sole plyometric execution, as this training method needs power training execution before doing plyometric, and it also would not make ethical problems for the coach or the researcher. Doing strength training in the onset of training period, probably by reducing the caused fatigue in the plyometric training, facilitates the compensation process and shortens the recovery time. Therefore, it is suggested that for getting good training results, especially in power fields, the strength training earlier of plyometric be used.

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