

Effects of plyometric training on soccer players (Review)

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Abstract. Plyometric training (PT) is a technique used to increase strength and explosiveness. It consists of physical exercises in which muscles exert maximum force at short intervals to increase dynamic performances. In such a training, muscles undergo a rapid elongation followed by an immediate shortening (stretch-shortening contraction), utilizing the elastic energy stored during the stretching phase. There is consensus on the fact that when used, PT contributes to improvement in vertical jump performance, acceleration, leg strength, muscular power, increase of joint awareness and overall sport-specific skills. Consequently, PT which was primarily used by martial artists, sprinters and high jumpers to improve performances has gained in popularity and has been used by athletes in all types of sports. However, although PT has been shown to increase performance variables in many sports, little scientific information is currently available to determine whether PT actually enhances skill performance in soccer players, considering that soccer is an extremely demanding sport. Soccer players require dynamic muscular performance for fighting at all levels of training status, including rapid movements such as acceleration and deceleration of the body, change of direction, vertical and horizontal jumps, endurance, speed as well as power for kicking and tackling. In this review we discussed the effects of PT on soccer players by considering gender and age categories.

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1. Introduction

Plyometric training (PT) consists of dynamic and rapid stretching of muscles (eccentric action) immediately followed by a concentric of shortening action of the same muscles and connective tissues (1). This training focuses on learning to move from a muscle extension to a contraction in a rapid or 'explosive' manner, such as in specialized repeated jumping. Exercises are of high-intensity, explosive muscular contractions combining strength and speed for acquisitions of benefits in power. PT involves hops and jumps used to capitalize on the stretch-shortening cycle of the muscle (1). The stored elastic energy within the muscle is used to produce more force than can be provided by a concentric action alone. It is distinguished by a rapid deceleration of mass followed immediately by its rapid acceleration in the opposite vertical direction. For the lower limbs, PT entails exercise such as hopping, bounding or drop-jumping (depth jumping) from a raised box or platform and immediately jumping vertically after an 'amortization' period of ground contact (2). The PT programme typically includes sport-specific exercises including exercises for shoulder and muscles of arms (3,4) and has traditionally been used for sprinting, jumping, and sports with rapid changes in direction.

The adaptability of PT has increased in popularity, thereby proven valuable for application to a range of sports as an effective tool in increasing lower body power (5), as measured in several studies using adult subjects (6). However, it has been reported that PT may also have negative aspects, particularly in its early phase. High intensity and repetition of eccentric contraction lead to a delayed onset of muscle soreness (7). In addition, only athletes who have already achieved a high level of strength through standard resistance training should engage in plyometric drills (8). It has been also shown that gains in jump performance following PT were due to change in mechanical properties of muscle-tendon complex more than to muscle activation (9). Taken altogether these data suggest that PT may constitute a high risk of injury of the youth growth plate (6,10) and may contraindicate them. Additionally, vigorous movements that incorporate sprinting, jumping and throwing actions (11,12) in PT may be damaging for youth subjects or adult females, even if improvements in balance, coordination and agility and injury prevention after use throughout pre-season training are likely, although the suggestion is less well supported by experimental evidence. Nevertheless, data demonstrating the use of PT for developing

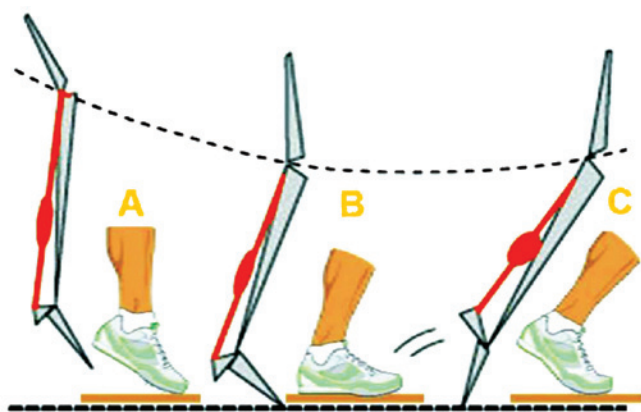


Figure 1. Basis of PT. The three basis phase of PT include: phase I or eccentric (A) correspond to the preactivation phase or stretch of agonist muscle. Elastic energy is stored in the series elastic component. Muscle spindles are stimulated; phase II or amortization (B) is the pause between phases I and III. Type Ia afferent nerves synapse with α motor neurons. α motor neurons transmit a signal to agonist muscle group. The phase III or concentric (C) is the shortening of agonist muscle fibers. Elastic energy is released from the series elastic component. α motor neurons stimulate the agonist muscle group. PT, plyometric training.

skill performance in soccer players (13), particularly in youth and female players, are available, although there is currently little scientific information available regarding whether PT actually enhances skill performance in soccer players. The purpose of this review was to examine the effects of PT on soccer player in young and adult athletes of both genders.

2. PT and its effects on body performances

Primarily used by martial artists, sprinters and high jumpers to improve the performances of athletes, PT has emerged in two forms that have evolved since 1980. An original version defined as the 'shock method' was created by the Russian scientist Yuri Verkhoshansky, the second version is widely used in the United States (?). In the first form, the athlete is required to drop down from a height and experience a 'shock' upon landing. This in turn led to a forced eccentric contraction, which was then immediately switched to a concentric contraction as the athlete jumped upward. The landing and take-off were executed in an extremely short period of time (0.1-0.2 sec). The shock method is the most effective method used by athletes to improve their speed, quickness, and power after development of a strong strength base. The second version of pyometrics widely used in the United States, relates to doing any form of jump regardless of execution time. This involves jumps that are lower in intensity and execution, while the time required for transitioning from eccentric to the concentric contraction is much greater.

Currently, typical PT comprises three phases (Fig. 1). The first phase is a rapid muscle lengthening movement known as the eccentric phase. The second involves a short resting period known as the amortization phase and, in the third phase, the athlete engages in an explosive muscle shortening movement, termed the concentric phase. The athlete repeats this three-part cycle as rapidly as possible, with the goal being to decrease the amount of time in between the eccentric and concentric movements. Reductions of time in between

eccentric and concentric movement induce the athlete to become faster and more powerful (14) as this primarily improves muscular, tendon and nerve functions (14). The increase in physical power make athletes run faster, jump higher and hit harder and develop specific skills such as injury protections relative to specific practiced sport (15). In addition, the forces involved and the quickness of execution induced the involvement of the central nervous system (16).

Benefits of PT in adult male and female athletes. Effects of a jump training program on landing mechanics and reduced extremity strength involved in jump sport were tested in female athletes who were compared prior to and after training with male athletes (17). Female athletes demonstrated lower improvements compared to males (17). These data concurred with previous studies, which also reported a higher incidence of serious knee injury in female participants in jumping sports compared with male participants (18-23). Accordingly, female athletes in jumping sports had significantly more minor and severe injuries, with 18% of girl injuries being knee-related compared to 10% boys in high school, and 89% of surgeries performed on female basketball players were for knee injuries as well as a 4-fold higher incidence of serious knee ligament injuries in female versus male national championship level of volleyball games (18). In professional basketball, a two-year study showed that the incidence of knee injuries in female players was 2.2-fold more than that in male players (22). These findings suggested that although women were as well trained as their male counterparts, differences in knee injury frequency remained.

By contrast, similar total injury rates of the patella and joints (24) reported for male and female collegiate athletes (24) or women and men (23) was attributed to differing levels of training (24) or sport practiced (23) and coaching, but not to anatomic or physiologic differences. Although studies attributed injury rate differences to structural differences, such as increased joint laxity in women (22,24), others refute this claim (23). By contrast, authors of two studies argued that estrogen is directly involved in increased injury rates in female athletes (19) or differences in pelvic structure and lower extremity difference between men and women (22,24). Notably, jump training programs incorporating stretching, PT exercises and weightlifting have been advocated to increase performance and decrease injury risk in competitive athletes in jumping sports (25). PT exercises are also clearly relevant in activities that demand high production and an important component in preparing for performance in a sport where jumping ability and large power output are not the major requirements. For example, in cross-country experienced male runners, in which the explosive strength training replaced 32% of the conventional training volume (26), improvement of their performances over 5 km was associated with the result of incorporating PT into their programmes. Improvements were attributed to changes in running economy (RE; a metric of efficiency commonly defined as submaximal oxygen consumption evaluated in milliliters per minutes per kilogram at a given velocity (27) that were reflected by reduced oxygen uptake at a fixed exercise intensity. Accordingly, any improvement in the RE referred to performance improvements because of the decreased oxygen consumption for a given distance, sparing

of muscle glycogen, decrease in fatigue, and the ability to sustain higher velocity. This improved economy approach was achieved by means of change in tendon stiffness at the ankle joint caused by weight training (9). Improvements in the RE related to PT exercises have been frequently demonstrated in recreational male and female runners to some extent but not all running speeds, without significant changes in the maximum volume of oxygen consumed per unit time ($\text{VO}_2 \text{ max}$) (28). Similarly, in experienced male middle and long distance runners PT improved velocity by 5.7 and 4.1%, respectively, after PT regimens of 6 and 9 weeks, respectively (29).

Benefits of PT in young subjects and adolescents. Findings supporting the benefits of repeated and intense physical efforts in young subjects and adolescents, thereby improving motor skills and body composition in terms of reducing fat mass and enhanced bone health, particularly if sport practice began early, when subjects were pubescent, have been previously identified (30-36). These benefits enhance sports performance, and better prepare young athletes for the demands of practice and competition. However, age should be considered for both pre-pubescent and elderly because of hormonal changes, even if it can be concluded that strength training is a relatively safe and healthy practice for children and adolescents.

Despite earlier concerns regarding the safety and efficacy of youth strength training, children and adolescents should include fitness exercises in their training routine (30-38). Fitness activities may be generated towards the strength, endurance, and flexibility requirements of the specific sport, but should not exclude other components of well-rounded general fitness. Plyometrics are intense by nature with a lot of load on joints, tendon and muscles (11,12) and it is recommended that adding PT exercises to a routine (8) of an athlete be delayed until strength and flexibility have been built up with regular cardio, weight training and stretching (6,10). Therefore, plyometrics are not inherently dangerous, but the highly focused and intense movements used in repetition may increase the potential level of stress on joints and musculotendinous units. Thus, safety precautions are strong prerequisites to this particular method of exercise. Low-intensity variations of PT are frequently utilized in various stages of injury rehabilitation, indicating that the application of proper technique and appropriate safety precautions can make plyometrics safe and effective for many categories of people.

Authors have previously identified that, female athletes who participate in pivoting and jumping sports are 6-fold more likely to suffer non-contact anterior cruciate ligament injuries compared to male athletes (39-41). Notably, after 8 weeks of PT training, there was alteration of lower limb kinematics and an increased eccentric hip torque and functional performance in young healthy recreational female athletes, compared to controls who carried out no physical training (42). These data suggested the necessity to incorporate PT in preventive programs for anterior cruciate ligament injuries.

3. PT and soccer players

Soccer is an intermittent, highly-intensive and complex sport. A successful performance is dependent on basic abilities, in particular, repeated explosive burst, strength, power, kicking,

tackling, and their derivatives such as jumping, turning, sprinting, and changing pace (43), all making important contributions to the performance of the soccer player. Nevertheless, soccer relies primarily on aerobic metabolism for energy, and it has been suggested that up to 98% of the total energy expenditure during 90 min of the game play is derived from aerobic metabolism (44). Aerobic endurance performance in soccer is governed by three interrelated mechanisms including, $\text{VO}_2 \text{ max}$, lactate threshold and RE (45). The average intensity is high, with a range of 75-80% of $\text{VO}_2 \text{ max}$, despite periods of recovery (46,47). Consequently, maximal oxygen consumption corresponds to the most important component of aerobic endurance performance in soccer (44), and there is evidence that indicates maximal aerobic power correlates with soccer success (46,48). Accordingly, a plyometric agility training program may increase the percentage of $\text{VO}_2 \text{ peak}$ in female soccer players (47), increase several muscle powers and endurance measured after a 6-week PT program in young soccer players (49) and improve and maintain the soccer kick for ball speed (50), thereby confirming the place of PT in skill performance (51) and decisive determining of neuromechanical training responses in high-level soccer players (52).

In line with the abovementioned data, strength prior to PT intervention is also an important variable (53) to consider as men tend to be stronger than women (54). Additionally, in non-trained individuals, men gain in vertical jump performance compared to women after PT (54) while similar sprint (55) and endurance (56) performance adaptation are reported in men and women after PT. This difference suggests that PT-induced adaptation occurred in men and women independently of the initial performance prior to training (57) or basal differences in important performance-related hormonal markers (58). However, in young (~21 years) players with a similar training load and competitive background assigned to training women and men, and control men and women groups, no differences in performance improvement was observed between the PT groups (59). The two PT groups improved more in all the performance tests compared to the controls group, suggesting that adaptation to PT does not differ between men and women. In addition, short-term (6 weeks) PT intervention induced higher maximal-intensity exercise and endurance performance improvements compared to soccer training alone, and the improvements induced by PT were not affected by gender (60). Thus, male and female soccer players with similar competitive background and training load can undergo similar PT programs (60). Accordingly, PT induced significantly greater kicking distance in a group of adolescent females (~13 years) after 14 weeks of training while no significant difference was seen in vertical jump height between the groups at pretest (61). PT improved depth vertical jump performance, agility and isometric knee extensor strength (62) in young soccer players.

4. Conclusion

Due to the multifaceted nature of physical requirements in soccer, including strength, endurance, power and agility, soccer training must be able to fulfill the needs of improvement. Taken altogether, the data demonstrated a strong ability of PT to transfer and improve specific cardiovascular and neuromuscular fitness. PT induces an increase in $\text{VO}_2 \text{ max}$,

maximal strength, sprinting speed, solid kick, endurance, agility, particular soccer player skills and vertical jump ability (63) in male and female individuals at any age, whether in recreational or professional athletes. In addition, improvements include muscular and tendon strengthening, resulting in the ability to avoid injuries (15).

Thus, PT must be a part of soccer player training programs as is the case in many types of sports. Safety consideration must be taken into account, including, evaluation of the athlete, ensuring facilities and equipment are safe, establishing sport-specific goals, determining program design variables, and teaching the athlete proper technique and properly promoting the program.

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