Title of the Article

The Effects of Plyometric Training on Change of Direction Ability: A Meta Analysis

Submission Type: Original Investigation

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Abstract

Purpose: The purpose of this systematic review with meta-analysis was to show a clear picture about the possible variables to enhancements of change of direction (COD) ability using longitudinal plyometric training (PT) studies and determines specific factors which influence the training effects. ***Methods***: A computerized search was performed, and therefore 24 articles with a total of 46 effect sizes (ESs) in experimental group and 25 ESs in control group were conducted to analyze the role of various factors on the impact of PT on COD performance. ***Results***: The results showed that participants with good fitness level obtained greater improvements in COD performance ($p < 0.05$), and basketball players gained more benefits of PT compared to other athletes. Also men obtained similar COD results to women following PT. In relation to the variables of PT design, it appears that 7 weeks (with 2 sessions per week) using moderate intensity and 100 jumps per training session with 72 h rest interval tends to improve COD ability. Performing PT with combination of different types of plyometric exercises such as drop jumps (DJ) + vertical jumps (VJ) + standing long jumps (SLJ) is better than one form of exercise. ***Conclusion***: It is apparent that PT can be effective at improving COD ability. The loading parameters are essential for exercise professionals, coaches, strength and conditioning professionals with regard to the most appropriate dose–response trends to optimize plyometric-induced COD ability gains.

Keywords: Effect size, lower limb, quickness, stretch shortening cycle

Introduction

Agility has been defined as a rapid whole body movement with change of velocity or direction in response to stimulus [1]. A comprehensive definition of agility recognizes the physical demands (strength and conditioning), cognitive process (motor learning) and technical skills (biomechanics) involved in agility performance [1]. Change of direction (COD) ability refers to a movement where no immediate reaction to a stimulus is required, thus the direction change is pre-planned [1,2], and is affected by strength, power and speed [1,2]. This ability is required in a range of sports such as running between bases in softball or baseball, running between wickets in cricket, and in some plays in American Football [3-7,8]. While agility movements involve responding to a stimulus [1], COD ability may influence agility performance in various sports such as invasion sports. However this article will focus on the effects of plyometric training (PT) on COD ability. Previous studies examined the influence of different types of training methods, including resistance training, PT and combined PT and resistance training on the development of COD performance [1,3,4,7-11]. A popular training method for improving COD performance is PT, because it has been established as an effective, time-efficient and easy way to implement training [3,5,11].

Plyometric training refers to exercises that are designed to enhance muscle, mainly through the use of jump training [12,13]. Plyometric exercises constitute a natural part of most sport movements because they involve jumping, hopping, and skipping [12,13]. The identifying feature of plyometric exercise is a lengthening (eccentric contraction) of the muscle-tendon unit followed directly by a shortening or concentric contraction, otherwise termed a stretch-shortening cycle (SSC) [13]. The SSC is integral to plyometric exercise because it enhances the ability of the muscle tendon unit to produce maximal force in the shortest amount of time [13,14].

The effects of PT may differ depending on the various subject characteristics (i.e., training level, gender, age, sport activity, or familiarity with PT) and training variables (i.e., surface of PT, rest interval between sets and training sessions, type of PT, and the principle of specificity) [3,4,5,6,7,11,15,17-32]. For example, jumping exercises that were nonspecific to COD (i.e., vertical-type jump exercise) did not cause any effect on COD performance [7]. When exercises were specific (e.g., lateral bounds, side hops, angles hops) to COD, the training program had a positive effect on COD performance [3,4,6,7,11,15,16].

In the literature, a number of studies investigated the influence of PT on COD ability and found improvements [3,4,5,6,7,11,15,17-32] and no changes [16,33] following a period of training. Although, studies exhibited improvements in COD ability (ranging from 0.3 sec to 1.89 sec using depth jump, countermovement jump, and mixed jump), the rate and magnitude of changes depends on several factors. The possible mechanism(s) to COD gains could be developments of force and high power output, as well as the ability to efficiently utilize the SSC in ballistic movements [3,4,5,23]. In contrast, a number of authors failed to report significant positive effects of PT on COD gains [16,33]. Further, the characteristics of a training program that achieves better gains are not clear [15,16,20-32].

Longitudinal PT studies combined some of these variables and found conflicting results on the magnitude of improvements in COD performance. In addition, other factors which affect the effectiveness of PT program may be duration and PT volume. In this case, studies have used numerous combinations of duration, intensity and volume characteristics. Therefore, the optimal combination of these factors for maximum enhancement in COD performance is not clear. In contrast to PT design, other variables which affect the rate of COD gain among studies may be different tests applied in PT studies. Some of those used T-test [3,4,11,15], Illinois agility test [3,4,15,20], shuttle run [3,21,25,33] etc and found different results. On the other hand, there are many tests to identify COD gains after PT, but the suitable test for measuring COD ability following PT has not yet been elucidated.

One of the important factors which affect the results of studies could be small sample size used in training interventions. Unfortunately, when studies are performed with small sample sizes that limit statistical power, they increase the likelihood of the researcher failing to express differences between treatments when in fact such differences exist. Typically, in PT studies the researchers used between 8 and 12 subjects in each training group [16,33], and this sample size is small to exhibit the effectiveness of PT on COD ability. Evidently, most PT studies had insufficient statistical power to detect not only small to moderate, but also large treatment effects. One method that allows us to overcome the problem of small sample size and low statistical power is the meta-analysis.

The meta-analysis is now widely accepted as the gold-standard for literature review and offers many powerful tools for clarifying research results in a particular topic. The steps of the meta-analytic review increase the scope, objectivity, and quantification of the overall body of literature on a particular topic [34,35]. Steps for thoroughly searching the literature, coding of study characteristics, extracting and standardizing data from individual studies, and statistically evaluating treatment effects make the meta-analysis a useful tool when attempting to draw conclusions about the research examining PT for COD improvements. This systematic review specially focuses on research on healthy individual on the effects of PT on COD performance. Although, there are many studies available, the beneficial effect of PT is not clear and or has not yet been elucidated. Does PT increase COD performance? If so, what type of PT is best suited for increased COD performance? What manipulation of the acute program variables (choice of exercise, volume, and intensity) is best? Therefore, the purpose of this systematic review with meta-analysis was to (1) examine the influence of various factors on the effectiveness of PT on COD performance and (2) establish the relative importance of various subject characteristics and training variables on COD improvement.

Methods

Subjects

To evaluate the effectiveness of PT for increases in COD ability, a meta analytic review was conducted. Literature searches were conducted electronically to find investigations which examined the effects of PT in COD ability. The research assessed ADONIS, ERIC, SPORTSDiscus, EBSCOhost, Google Scholar, MedLine and PubMed electronic databases between June and July 2014 and updated in September 2015. Moreover, manual searches were performed in sport sciences relevant journals. The references of identified articles were examined to identify additional studies that were eligible for the review. The search included all studies published in English and studies in any language for which the abstract was available in English. Key words used were (agility, agility training, agility performance, agility times, change of direction, plyometric training, plyometrics, neuromuscular training, explosive training, power training, jump training, stretch shortening cycle and quickness). No age or gender restrictions were imposed during the search stage.

Methodology

For the selection of studies to further review, we performed 3 steps; 1) the title of the articles were read, 2) the abstracts were read, and 3) the whole articles were read. In this review only human studies and full primary research papers (i.e., not a conference abstract, letter to editor, thesis or review) were eligible for inclusion. In addition, only PT using lower limb exercises were used, and upper body PT programs were excluded.

Studies were included if they met the following criteria based on recommendation by Campbell and Stanley [36]; 1) randomized control studies, 2) high validity and reliability instruments, 3) published in a high quality peer-review journal, 4) chose athletes or physically active, healthy participants, 5) studies where the PT program was described, and 6) studies where COD test were measured before and after training. Following these search process, 24 articles were included in the analysis [3,4,5,6,7,11,15,17-32] (Table 1 and Fig. 1).

(Insert Table 1 and Figure 1 about here)

Each article was read and coded by two investigators for the following variables: 1) descriptive information (age, body mass, height and group size), type of population (team and individual), practice of plyometrics (familiarized and not familiarized), fitness level (good, normal and regular), gender (male, female and both), and sport activity (physically active, soccer, rugby, basketball, water polo, and none); 2) program exercises: type of exercise (aquatic PT, land PT, mat PT, grass PT, sand PT, vertical PT, horizontal PT, bilateral PT, unilateral PT, progressive PT, and no progressive PT), intensity of exercise (low, low to moderate, moderate, moderate to high, and high), type of plyometric (depth jump [DJ], countermovement jump, DJ-vertical jump-standing long jump, hurdle jump, and mixed model [combination of different plyometric exercises]), rest between sets (30, 60, 90, 120 and 180 sec), and rest between training sessions (24, 48 and 72 h); 3) program variables: frequency of weekly sessions, program duration and number of total jumps; and 4) outcome measurements the type of COD test used to identify performance gains (e.g. T test [TT], Illinois agility test [IAT], Shuttle run (SR), 505, L-run, 10×5-m, and 10-m). The mean agreement was calculated by intraclass correlation coefficient (ICC). The coding agreement between investigators

was determined by dividing the variables coded by the total number of variables. A mean agreement of 0.90 is accepted as an appropriate level of reliability for such coding procedures [37]. The mean agreement between coding for this study was 0.96. Any coding differences between investigators were scrutinized and resolved a priori to the analysis.
Gain Effect Size (ES) were calculated using Hedges and Olkin´s *g* [37], using the formula (1): $g = (M_{post} - M_{pre}) / SD_{pooled}$, where M_{post} is the mean for the post test and M_{pre} is the mean for the pretest, and SD_{pooled} is the pooled *SD* of the measurements (2):

$$SD_{pooled} = \frac{(M_{post} - M_{pre})}{\sqrt{((n_1 - 1)\cdot SD_1^2 + (n_2 - 1)\cdot SD_2^2)/(n_1 + n_2 - 2)}}$$

The ES is a standardized value that permits the determination of the magnitude of the differences between the groups or experimental conditions. It has been suggested [38] that ES should be corrected for the magnitude of sample size of each study. Therefore, correction was performed using formula (3): $1-3 / (4m-9)$, where $m = n - 1$, as proposed by Hedges and Olkin [37].

Statistical Analyses

To determine the effects of the categorical independent variables (type of populations, practice of plyometrics, fitness, gender, sport activity, and program exercises [type of exercise, intensity of session, type of plyometric, rest between sets and training sessions]) on the COD ability ES, an analysis of variance (ANOVA) was used [34,35,38]. In the case of quantitative independent variables (e.g., age, height, duration of the treatment in weeks, number of total jumps) a Pearson's (*r*) correlation test was used to examine the relationships between COD ESs and variable values [39]. The α level was set at $p \leq 0.05$ for statistical significance. In addition, data was also assessed for clinical significance using an approach based on the magnitudes of change. Threshold values for assessing magnitudes of ES were < 0.35, 0.35-0.80, 0.80-1.50 and > 2.0 for trivial, small, moderate and large respectively [38] (Fig. 2).

(Insert Table 2 and Figure 2 about here)

Results

The analysis showed that the average ES of the experimental group (0.96; $n = 46$; -0.68 sec) was significantly higher ($p < 0.05$) compared to the ES of controls (-0.02; $n = 25$; 0.02 sec).
With regards to the subjects characteristics, the results indicate a significant correlation coefficient for body mass ($r = 0.316$), and height ($r = 0.425$) with the magnitude of the ES and no significant correlation coefficient for age ($r = 0.260$) and group size ($r = 0.185$) with the magnitude of the ES (Table 2). The ANOVA showed significant effects in some of the variables measured (i.e., fitness level, $p = 0.017$ and sport activity, $p =$

0.027). However, there was no significant effect ($p < 0.05$) in the variables of gender and practice of plyometrics.

(Insert Table 3 about here)

The ANOVA showed no differences in ESs regarding the intensity of session (p = 0.372), the type of exercises (p = 0.818), the rest between training sessions (p = 0.384) and rest between sets (p = 0.338). However, significant differences were found among the type of plyometrics (p = 0.002) (Table 3).

There was no significant relationship ($p < 0.05$) between the frequency session/week (r = 0.139), program duration (wk) (r = 0.063) and number of total jumps (r = 0.140) with COD ES (Table 4). No differences in ES (p = 0.799) were found among the different COD tests (Table 5).

(Insert Tables 4 and 5 about here)

Discussion

The primary aim of this systematic review was to determine the effectiveness of PT interventions on COD performance. In addition, the secondary aim of this review article was to establish the relative importance of various subject characteristics and training variables on COD gain. Through meta-analytic procedures, the body of literature examining this form of exercise becomes much clearer, and many key points of knowledge are identified. This systematic review of 24 PT studies suggests that PT (in water, sand, grass or land surface) improves COD ability and that the mean effect ranges from ES =0.26 (i.e., small effect) to ES =2.8 (i.e., large effect) depending on the type of COD test measured. The findings of this systematic review (ES=0.96; i.e., plyometric group) are in line with previous studies [3,4,5,6,7,11,15,17-32] that used PT for the COD gains and found that PT is an effective training interventions to significantly improve COD performance (> -0.68 sec). These data suggest that there may be a positive transfer of the effects of PT on COD ability to athletic performance like basketball.

It has been well documented that performing PT requires sufficient muscle strength and coordination as well as appropriate technically ability [4,5,17,18]. In the present study, three subgroup analyses were performed for outcomes. We found a significant difference in the effects of PT on COD ability between good versus normal or regular fitness level, which indicates previous strength, coordination, and neuromuscular function has positive effects on training outcome and consequently enhancement of COD ability [3,4,23]. However, the differences in COD gains were not statistically different between familiarized and not familiarized subjects (Table 2). In this study, we found that team sport athletes (i.e., basketball players) gained greater enhancements in comparison to other sports. Likewise, we found positive effects of PT for the COD enhancements in untrained, not familiarized and or poor fitness level subjects. The possible mechanism(s) during the initial weeks in power-type strength training or PT could be neuromuscular adaptations [3,4,39]. Neural adaptations and enhancement of motor unit recruitment are mechanisms that can lead to an increase of the COD tests [39]. Improvements in COD requires rapid force development and high power output, and it seems that PT can improve these requirements [1,15]. In addition, the PT may have improved the eccentric strength of the thigh muscles, a prevalent component in change of direction during the deceleration phase [1]. Moreover, COD tasks require a rapid switch from eccentric to concentric muscle action in the leg extensor muscles (the SSC muscle function). Thus, it has been suggested that SSC training (PT) can decrease ground reaction times through the increase in muscular force output and movement efficiency, therefore positively affecting COD performance [40].

In the present study, three subgroup (gender: Male, Female and Both) analyses were performed for outcomes. We found no significant difference in the effects of PT on COD performance between male and female. On the other hand, men demonstrated similar gains in comparison to women (Table 2); however, this finding is probably the result of an insufficient number of studies on performed PT (42 vs. 2). Based on previous studies [34,35] the percentage of improvements in performance is higher for men compared to women. Previous authors indicated that men had a greater SSC ability than women [41]. However, we found minimal differences between men and women in ESs (0.98 vs. 0.97) and time gains (-0.67 vs. -0.92 sec). Very recently, in accordance with our findings, Ramirez-Campillo et al. [29] examined the effects of 6 weeks PT on COD ability (i.e., IAT) in men and women soccer players and found that both the experimental groups increased their COD ability and there were no significant differences between them in COD gains (ES, 0.46 vs. 0.85; time gain, 0.75 vs. 0.4 sec).

Our results suggest that higher enhancements after PT can be observed in Basketball players compared to those gains reached in other athletes such as soccer or rugby (Table 2) players. It seems that PT was more specific for basketball compared to other sports. Perhaps the nature of basketball sport (horizontal and lateral running, fast and quick movements in between opponent players for crossing the ball) [4] induced greater responses to PT and consequently more COD enhancements.

In the present study, COD ability gains were not statistically significant higher when plyometrics were performed in different surfaces (i.e., Aquatic or Sand surface) and type of intervention (i.e., PPT, UPT, BPT, HPT, VPT and etc). However, it should be mentioned that when plyometrics were performed in aquatic or sand surface, higher ESs were observed (Table 3). In comparison to our results, previous studies reported that performing plyometrics in water environments were better than land or mat surfaces [4] and sand PT was superior to land PT [23,24] in improving COD ability. The common mechanisms for the greater enhances in COD via PT on aquatic or sand surface could be greater neural adaptations and enhancement of motor unit recruitment [42,43]. Performing PT on this surface induces more work for the muscle fibers to overcome the mobilization of resistance [42,43,44,45], thus these variables could be one of the possible mechanisms to improve COD task.

Intensity of exercise session plays a critical role in further adaptation. In previous studies, some authors reported that when the intensity was high during a session, there was a greater improvement in muscular performance [20,34,35]. Previous researchers addressed that low intensity of PT induced greater increases compared to moderate intensity in COD ability [17]. In the current meta-analysis, COD ability gains were not significantly higher when plyometrics were performed with high intensity, whereas we found greater, but not significant, gains for the low and moderate intensities in COD performance (Table 3).

The results of this study showed that a combination of DJs, VJs, and SLJs demonstrated a higher ES compared to single type of exercise (e. g., DJs and CMJs) and or mixed plyometric exercises (Table 3). This was mainly because of the different characteristics of movement and, thus, different use of SSC characteristics. For this reason, the combination of various exercises (DJ, VJ, and SLJ) may result in greater COD gains compared to the other exercises. Selecting the appropriate plyometric exercise for COD improvements is very important. It has been well reported that PT is an effective training method to improve muscular performance because it enhances the ability of subjects to use the elastic and neural benefits of the SSC [34,35,39]. The SSC are affected by different types of plyometric exercises such as; fast SSC jumps (i.e., DJ) or concentric-only jumps (e.g., SJ), or even slow SSC jumps (i.e., CMJ), and it seems that adaptations to these type of exercises are different (ES; DJ=0.79 vs. CMJ=1.53). PT induced the rapid development of maximal force during the eccentric phase of motion [4]. It has been previously reported that PT with different exercises can influence the rate of adaptation and consequently greater improvements in COD performance [3,4,11,20], which is in agreement with our findings.

The results of the study indicated that there were no significant differences in rest interval between sets and magnitude of changes in COD performance. However, the rate of changes and improvements were higher for the 120-s (ES=1.26) rest between sets in improvement of COD ability. To the authors knowledge, Ramirez-Campillo et al. [26] examined the effects of 6 weeks PT using 30, 60, or 120 s of rest between sets on COD ability (i.e., L-run) in young soccer players and found that all experimental groups improved COD ability (moderate ES) and the rate of enhancement was greater for 120 s of rest between sets (ES=1.04). The possible greater enhancement, although not significant, in COD via applying 120-s rest interval between sets may have been due to several possible mechanisms such as better phosphocreatine resynthesis, clearance of by products (e.g. lactate, H+ ions), regulation of acid-base balance, reconstitution of maximal power output, and these mechanisms may allow better recovery from PT and consequently gains in COD performance [46,47].

In the recent study by Ramirez-Campillo and coworkers [18] the effects of inter-day rest on COD (i.e., 10×5) ability following 6 weeks of PT was determined. Those authors reported no significant differences between 24 and 48 h rest on COD performance, but the ES of 24 h rest was minimally greater than 48 h rest (0.63 vs. 0.57). The results of the current meta-analysis showed that 72 h of rest between training sessions was better than other times such as 48 and or 24 h (Table 3). It seems that 72 h rest between plyometric training sessions was appropriate to allow for adequate recovery, suggesting that these time frames of rest would be necessary to induce adequate training stimulation. The possible mechanisms could be due to gains in COD with 72 h rest interval between training sessions includes more changes in the contractile apparatus of the muscle fibers, better neural adaptations such as leg muscle activation strategies, inter-muscular coordination, stretch reflex excitability, greater changes in muscle architecture (i.e. a decrease in fascicle angle and an increase in fascicle length of knee extensors), and better changes in stiffness of various elastic components of the muscle-tendon complex [48,49].

The limitation of this review was the number of articles that met the inclusion criteria. Although all articles included provide evidence that PT may improve COD performance, further research is necessary to elucidate the most effective of PT on COD ability.

Typically, designing an optimum PT program is related to training load (volume and intensity) and frequency of training. In this study we did not find significant correlations between frequency, number of jumps and program duration on COD gains (Table 4) and we cannot strongly recommend optimum training variables to achieve COD ability. However, overall a short-term PT program for 7 weeks and 14 sessions performing ~ 1350 jumps (100 jumps per session) with moderate intensity and 72 h rest between training sessions tended to induce COD ability gains.

Practical Applications

Plyometric training can be recommended as an effective form of physical conditioning for enhancing the COD ability; yet, the effects of PT could vary because of a large number of variables, such us program duration, training volume, rest interval or intensity and subject characteristics (gender, age). These variables should be taken into account by strength and conditioning professionals to design an optimum PT program to enhance COD ability for a given sport. Therefore, in addition to the well-known training methods such as strength and power training in the weight room, strength and conditioning professionals may well incorporate PT into an overall conditioning program of athletes to achieve a high level of COD performance.

Conclusion

In conclusion, the current meta-analysis demonstrates that PT significantly improves COD performance. The estimated improvements in COD as a result of PT could be considered as practically relevant—for example, an improvement in COD time of > -0.68 seconds (i.e., ES = 0.96) could be of high importance for athletes in sports relying on COD ability. According to our meta-analysis results, when subjects can perform plyometric exercises with adequate technique and have good fitness level the training gains are better, although the rate of COD gain is similar in men and women after PT. In relation to the variables of PT design, it appears that 7 weeks (with 2 sessions per week) using moderate intensity and 100 jumps per training session with 72 h rest interval tends to achieve improvements in COD ability. Another important conclusion is that there is a minimal profit to perform PT in water or sand environment, and that it is more beneficial to combine plyometrics (DJs + VJs + SLJs) than to utilize only the single modality.

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Tables and Figure Legends

Figure 1. Criteria for selection of articles for review.

Figure 2. Effects size (ES) of all studies meeting the inclusion criteria.

Table 1. Summary of characteristics of all studies meeting the inclusion criteria.

Table 2. Analysis for independent variables of subject characteristics

Table 3. Analysis of variance results on the differences of ES between various elements of plyometric training independent variables of program elements

Table 4. Pearson correlation coefficients (r) between various program elements and training gains

Table 5. Analysis for independent variables of outcome measurement.