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Handball research: State of the art

Effects of Short-Term Plyometric Training on Physical Performance in Male Handball Players

by
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The aim of this study was to compare the effects of plyometric and jump training on physical performance in young male handball players. Twenty-six young male handball players were divided into two sub-groups to perform a five-week pre-season training programme supplemented with two ground-reactive protocols with an equal number of jumping exercises referred as to ground contacts: plyometric training (PLY; n = 14) and standard jump training (CON; n = 12). Before and after training, repeated sprint ability (RSA), jumping ability (JA), maximal oxygen uptake (VO2max) and aerobic power at the anaerobic threshold (PAT) were measured. A two-factor analysis revealed significant time effects with improvements in fat mass (p = 0.012), maximal power during the incremental cycling test (p = 0.001) and PAT (p < 0.001), power decline (PDEC) and maximal power (Pmax) in the 5th repetition (p < 0.05 and p < 0.01, respectively). The training-induced changes in absolute and relative peak power in the RSA test and absolute VO2max approached significance (p = 0.06, p = 0.053 and p = 0.06). No intervention time × exercise protocol effects were observed for any indices of JA, RSA and aerobic capacity. A five-week pre-season conditioning programme supplemented with only 15 sessions of plyometric exercise did not induce any additional benefits, compared to a matched format of standard jump training, in terms of improving jumping performance and maximal power in the RSA test. Aerobic capacity and the fatigue index in RSA were maintained under these two training conditions.

Key words: *plyometrics, jumping, youth, repeated sprint ability, team sport.*

Introduction

Team handball is classified as a high-intensity, body-contact sport that demands a high level of aerobic and anaerobic fitness. For handball players, successful match performance requires several physical attributes such as speed, power, strength and agility, plus the ability to maintain performance during repeated sprints (Michalsik et al., 2013).

Training for most sports requires different physical qualities to be emphasized across an annual period, with the overall goal to improve sports performance during competition. During the pre-season period, handball training emphasizes the development of physical fitness, whereas the in-season period is aimed at maintaining aerobic and anaerobic capacity and improvement of tactical and technical skills. As a result, one of the aims of pre-season training is to improve jumping ability, repeated sprint ability (RSA) and aerobic endurance.

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It is common practice to include plyometric exercises in a regular training programme to increase strength and explosiveness (Chelly et al., 2014) or RSA (Chtara et al., 2017). Plyometric exercises involve rapid stretching (i.e. lengthening) of a muscle immediately before a rapid concentric contraction. This combined action is commonly called the stretch-shortening cycle (SSC) (Hermassi et al., 2014). Plyometric training, when combined with a periodized strength-training programme, has been shown to increase many performance variables: vertical jump performance, acceleration, leg strength, muscular power, increased joint awareness, and overall proprioception (Slimani at al., 2016; Stojanović et al., 2016; Ziv and Lidor, 2010).

Short-term plyometric training (i.e. 2–3 sessions a week for 6–15 weeks) can change the stiffness properties of the muscle-tendon complex and improve lower-extremity strength, power and SSC muscle function in healthy individuals (Markovic and Mikulic, 2010). Nevertheless, this study did not provide definitive conclusions regarding the effects of plyometric training on more functional abilities likely to be expressed in sport (e.g. RSA performance). One of the recommended approaches is to combine plyometrics with traditional strength training (Dæhlin et al., 2016). However, there are limited scientific data regarding the effectiveness of combining regular and plyometric training.

Efficacy testing of a short-term (<6 weeks) training strategy to improve sport-specific performance in youth handball players would be of significant interest to coaches, practitioners and scientists alike. Therefore, the aim of this study was to compare the effects of plyometric and strength training on physical performance variables in young male handball players. Specifically, we examined whether a five-week pre-season plyometric programme would enhance aspects of physical performance in young athletes, relative to a standard jump training regimen.

Methods

Study design

Using a two-group design, 26 young athletes were assigned randomly to a plyometric training group (PLYO; n = 14) or a standard training group, which served as a control (CON; n = 12). Both interventions supplemented a normal handball training programme during the pre-season period. The 5-week pre-season period of training was assumed to be standard handball training appropriate for this sports level. Trial protocols consisted of the same numbers of jumping exercises, defined as a number of ground contacts. The only difference was the nature of the plyometric (stretch-shortening cycle included) or standard jumps (stretch-shortening cycle excluded). Performance was based on repeated sprint ability, aerobic capacity and vertical jump ability. The specific measurements included somatic data, vertical jump height during a countermovement jump (CMJ) and squat jumps (SJs), lower limb power during a drop jump (DJ) test, repeated sprint ability and aerobic capacity during two separate cycle tests. These data were collected two days before training began and within three days of completing the five-week intervention.

Participants

Twenty-four, healthy male handball players (mean ± SD: age = 20.2 ± 2.2 years; body height = 183.0 ± 5.4 cm; body mass = 86.0 ± 9.9 kg, training experience = 8.4 ± 6.3 years) from two teams were recruited for this study. All participants were competitive handball players, and were affiliated with two professional clubs competing in the second and third division of the Polish league. Institutional ethics approval from an Ethics Committee (Institute of Sport – National Research Institute, Warsaw, Poland) was given and individual written informed consent was obtained before study commencement.

Training

The training programmes for both groups included five conditioning sessions and three sport-specific team sessions per week, all performed under supervision. Individual resistance-training programmes for the upper and the lower limbs were completed twice a week. This training was supplemented with jump training, as defined by subject allocation into the PLYO and CON sub-groups. The training loads are presented in Table 1. The type of exercises that each group performed was matched by the number of jumps and, where possible, using similar jumps. The two groups performed the same number of jumps per session, the only difference being the body orientations after landing. Instructions for the PLYO group were to jump as high as possible, and keep minimum ground contact time, whereas the CON group was told to jump as high as possible, relax and improve the position after landing. Rest intervals between each jumping sets lasted 2 min.

Measurements

The initial and final performance measurements were made at the same time of day, and under the same experimental conditions, by the same group of researchers. Verbal encouragement was provided throughout all tests to ensure maximal effort.

Anthropometrics

The anthropometric profiles of subjects were taken in the morning wearing only light clothing. Height was measured with a standard stadiometer to the nearest 0.1 cm. Body mass (BM), absolute and relative fat mass (FM) and fat-free mass (FFM) were evaluated with an eight-electrode bioelectrical impedance device (Tanita Corp., BC-418 Tokyo, Japan), while in a standing position. The body mass index (BMI) was calculated as body mass (kg)/height^2 (m).

Aerobic capacity

Aerobic capacity was measured using an incremental protocol on a cycle ergometer (Lode Excalibur, Groningen, The Netherlands) with a calibrated volume sensor and a breath-by-breath gas analyzer (Mes 2000 M, Cracow) to determine maximal oxygen uptake (VO_{2max}), and maximal peak respiratory minute volume (VE_{max}). The device was calibrated in accordance with the manufacturer's instructions. The highest values of oxygen uptake, heart rate and minute ventilation maintained for 30 s were considered to be VO_{2max}, HR_{max} and VE_{max}, respectively. The exercise started at 50 W, increasing in steps of 50 W every three minutes until volitional exhaustion. Each test was completed within 24 min. Throughout exercise, blood collection began at 2 min 30 s of each three-minute stage and was completed before the start of the next step. Power output at the anaerobic threshold was determined by interpolation of the data on the 4-mmol blood lactate point.

Repeated sprint ability (RSA)

RSA was assessed using a cycle ergometer (Monark). The test consisted of 5 × 6 s maximal sprints every 30 s, with the load equal to 7.5% of the athlete's body mass. The athletes were instructed to pedal at the highest possible speed in each repetition. During the 24-s recovery between sprints, the participants rested. Straps were used to secure the feet to the pedals, and each sprint was performed in the seated position. Proprietary software (MCE 5.1. JBA Staniak, Poland) recorded peak power of each repetition; average peak power in five sprints and the fatigue index were calculated. The method used to determine total work and the decrement (%) in power and work has been described previously (Bishop et al., 2004). The cycling protocol provides both a valid (Bishop et al., 2001) and reliable test of RSA (Bishop et al., 2001). The coefficient of variation (CV) for RSA (total work; kJ) was 3.7%, based on a five-week separation period (similar to the current study) in recreationally active female students (Edge et al., 2005).

Jumping ability

Vertical jump height, based on the rise of the centre of mass, was calculated from the registered reactive force using a ground-built force plate with the MVJ v. 3.4 software package ("JBA" Staniak, Poland). Each subject performed nine maximal jumps on the top of the force plate with the aim to reach peak vertical height. The jumps included three squat jumps (SJs) with arms on the hips, three countermovement jumps with an arm swing (CMJs) and three drop jumps also with an arm swing (DJs). The subjects were given rest periods of 20 s between the CMJ and SJ trials, with a 60 s rest interval separating the DJ trials. Those jumps with the highest elevation of the body's centre of mass were selected for subsequent analysis.

Statistical analyses

Data are reported as means ± standard deviation (SD). A two-way mixed analysis of variance (ANOVA) was used for each continuous dependent variable. The independent variables included one between-subjects factor with two levels (PLYO and CON), and one within-subject factor with two levels (pre-training and post-training). The level of statistical significance was set at $p < 0.05$. Data processing and statistical evaluations were completed using SPSS version 20.0 for WINDOWS (SPSS Inc, Chicago, IL).

Results

Somatic features

The results of two-factor ANOVA for

somatic variables revealed only one significant main time effect for relative fat mass (p = 0.012); the percentage of FM was reduced significantly after the intervention, but the change was not training dependant. No significant time effect or group × time interactions were found for BM, BMI and absolute FM (Table 2).

Aerobic capacity

The two-factor ANOVA revealed a main time effect for maximal power in the incremental cycling test and aerobic power (power output at the anaerobic threshold), such that these indices increased significantly across the training period (Table 3). No time effect for VO_{2max} and VE, and no time x training interaction was observed for any indices of aerobic capacity (Table 3).

Anaerobic capacity and jumping ability

A significant time effect was found only for P_{DEC} and P_{max} in the 5th repetition ($p < 0.05$ and $p < 0.01$, respectively). P_{DEC} and P_{max} in the 5th repetition improved significantly after the intervention. The changes in average absolute and relative peak power in the RSA test did not reach statistical significance (p = 0.06 and p = 0.053). Significant time main effects were also found for the SJ and CMJ ($p < 0.05$ and $p < 0.05$, respectively), with both decreasing with training. The DJ performance did not change significantly in any group, nor were there any differences by training group. No significant group × time interactions emerged for any index of repeated sprint ability and jumping ability (Table 4).

Table 1

The five-week training program for plyometric and control groups.

Week	Session	Hurdles jumps	Vertical jumps	Stride jumps	Double leg multi-jumps (front hops; 76 cm)	Drop jumps (drop + rebound)	Drop to hurdle jumps (drop + hurdle)
	1	2 x 10	3 x 8		5 sets x 5 jumps	3 x 6 (20 cm)	
1	2	2 x 10		3 x 8	5 sets x 5 jumps	3 x 6 (20 cm)	
	3	2 x 10	3 x 8		5 sets x 5 jumps		3 x 6 (20 cm + 76 cm)
	4	2 x 10		3 x 8	5 sets x 5 jumps.		3 x 6 (20 cm + 76 cm)
2	5	2 x 10	3 x 8		5 sets x 5 jumps.	3 x 6 (40 cm)	
	6	2 x 10		3 x 8	5 sets x 5 jumps	3 x 6 (40 cm)	
	7	2 x 10	3 x 8		5 sets x 5 jumps	3 x 6 (40 cm)	
3	8	2 x 10		3 x 8	5 sets x 5 jumps		3 x 6 (40 cm + 76 cm)
	9	2 x 10	3 x 8		5 sets x 5 jumps		3 x 6 (40 cm + 76 cm)
	10	2 x 10		3 x 8	5 sets x 5 jumps		3 x 6 (40 cm + 76 cm)
4	11	2 x 10	3 x 8		5 sets x 5 jumps	3 x 6 (60 cm)	
	12	2 x 10		3 x 8	5 sets x 5 jumps	3 x 6 (60 cm)	
5	13	2 x 10	3 x 8		5 sets x 5 jumps	3 x 6 (60 cm)	
	14	2 x 10		3 x 8	5 sets x 5 jumps		3 x 6 (60 cm + 76 cm)

Table 2

Comparison of anthropometric indices between the plyometric training group and the control group before and after the 5-week intervention.

	Control group (n=12)		Plyometric group (n=14)		Effects	
	Pre	Post	Pre	Post	Time	Interaction (time x exercise)
Body mass (kg)	85.6 ± 9.6	85.7 ± 9.7	86.5 ± 10.2	86.6 ± 9.9	ns	ns
Body mass index	25.3 ± 2.4	25.2 ± 2.3	25.7 ± 3.5	25.7 ± 3.2	ns	ns
Fat mass (%)	15.3 ± 2.9	14.3 ± 3.9	17.0 ± 5.0	16.2 ± 4.9	0.012	ns
Fat free mass (kg)	72.5 ± 7.7	70.9 ± 10.6	71.5 ± 6.4	72.3 ± 6.7	ns	ns

Table 3

Comparison of aerobic capacity indices between the plyometric training group and the control group before and after the 5-week intervention.

	Control group (n = 12)		Plyometric group (n = 14)		Effects	
	Pre	Post	Pre	Post	Time	Interaction (Time x Exercise)
VE_{max} (l/min)	152 ± 39	148 ± 34	149 ± 32	154 ± 35	ns	ns
VO_{2max} (ml/kg/min)	45 ± 10	45 ± 13	43 ± 5	46 ± 6	ns	ns
VO_{2max} (l/min)	3.6 ± 0.8	3.8 ± 0.9	3.7 ± 0.4	4.0 ± 0.6	0.06	ns
Maximal load (W)	259 ± 33	277 ± 44	261 ± 16	278 ± 28	0.001	ns
Maximal load (W/kg)	3.1 ± 0.6	3.2 ± 0.7	3.1 ± 0.4	3.3 ± 0.5	0.003	ns
P_{AT} (W)	150 ± 27	168 ± 34	150 ± 21	171 ± 36	0.001	ns
P_{AT} (W/kg)	1.7 ± 0.4	2.0 ± 0.5	1.8 ± 0.3	2.0 ± 0.5	0.002	ns

Table 4

Comparison of RSA and jumping performance indices between the plyometric training group and the control group before and after the 5-week training intervention.

	Control group (n = 12)		Plyometric training group (n = 14)		Effects	
	Pre	Post	Pre	Post	Time	Interaction (Time x Exercise)
$P_{RSA\ max}$ (W)	853 ± 82	871± 94	880± 107	891 ± 98	0.06	ns
$P_{RSA\ max}$ (W/kg)	10.1 ± 0.9	10.2 ± 1.0	10.2 ± 0.6	10.3 ± 0.6	0.053	ns
P_{max1} (W)	911 ± 86	917 ± 99	930 ± 116	933± 105	ns	ns
P_{max1} (W/kg)	10.8 ± 1.2	10.8 ± 1.1	10.8 ± 0.8	10.8 ± 0.6	ns	ns
P_{Dec} (-)	12.6 ± 7.5	10.6 ± 4.5	11.3 ± 4.1	9.3 ± 2.3	0.04	ns
P_{max5} (W)	795 ± 93	812 ± 97	824 ± 99	84 ± 96	0.004	ns
P_{max5} (W/kg)	9.4 ± 0.9	9.6 ± 0.9	9.6 ± 0.5	9.8 ± 0.6	0.004	ns
SJ (m)	0.40 ± 0.08	0.39 ± 0.08	0.41 ± 0.04	0.40 ± 0.03	0.039	ns
CMJ (m)	0.45 ± 0.09	0.44 ± 0.09	0.47 ± 0.06	0.46 ± 0.05	0.026	ns
DJ (m)	0.52 ± 0.09	0.51 ± 0.09	0.55 ± 0.07	0.56 ± 0.06	ns	ns

Discussion

The main finding of this study was that a five-week customary pre-season training regimen (with plyometric exercises included) had a similar effect on repeated sprint ability, aerobic capacity and jumping ability as a programme that included standard jump training, when the same number of jumps were performed by young male handball players.

To date, most studies have investigated the effects of plyometric exercise added to standard training or instead of selected training loads on jumping ability, agility and endurance, yet separately. The present study is one of only a few that support data on how combining plyometric exercises and standard jumping with a regular, appropriate conditioning programme results in effectiveness of the pre-season handball training in improving simultaneously aerobic and anaerobic capacity. Beside increasing explosive power, developing aerobic fitness is an important factor influencing the ability to resist fatigue during RSA and VO_{2max} is significantly correlated with the RSA fatigue index in team sport athletes (Gharbi et al., 2015).

We expected a significant increase in jumping ability and sprint performance by combining regular handball training and plyometric exercises. Surprisingly, the jumping ability (SJ and CMJ) of subjects decreased in both the PLYO and CON groups. Previously, it has been shown that plyometric training can improve performance in various sports, by either combining it with regular training or using it separately to improve a specific physical component of the neuromuscular system (Slimani et al., 2016; Stojanović et al., 2016). Markovic and Mikulic (2010) reported that plyometric training, either alone or in combination with other training modalities, had the potential to enhance a wide range of performance aspects, including jumping, sprinting, agility and endurance performance, in children and young adults of both sexes. Thus, our results are contrary to several studies that have demonstrated that plyometric training can enhance muscle strength and power (Markovic, 2007a), speed (Hammami et al., 2016) and agility (Khodaei et al., 2017).

Jumping ability

We noted similar decreases in the SJ and CMJ in the PLYO and CON groups (SJ: 1.8% and 2.3%; CMJ: 1.9% and 2.3%). Only DJ performance increased in the PLYO group by 1.3% and there was a decrease in the CON group by 1.0%, but these differences were not significant. Chelly et al. (2015) found that 10 weeks of lower limb plyometric training, added to a standard in-season regimen, increased vertical (SJ, CMJ, and DJ) as well as horizontal jump ability more than standard training. With plyometric training, absolute peak power increased by an average of 9.1%, though similar gains (10%) were achieved using a standard training approach (Chelly et al., 2015). Generally speaking, one might expect greater gains from plyometric exercises. Stojanovic et al. (2016) demonstrated positive effects on SJ, CMJ and DJ performance in females that were small, moderate to large and very large, respectively. Some studies have demonstrated no change in jump height after a six-week plyometric training programme (Gottlieb et al. 2014) and 9-week training programme supplemented with plyometric exercises (Brito et al., 2014). Most authors have reported a beneficial effect (from plyometrics) with relevant improvements in jump height ranging from 4.7% (SJ and DJ), through 7.5% (CMJ with an arm swing) up to 8.7% (CMJ) (Markovic, 2007a). These results justify the application of plyometric exercises for the purpose of development of vertical jump performance in healthy individuals (Markovic, 2007a).

The conflicting reports and lack of improvements in our study participants could be explained by several factors. Slimani et al. (2016) hypothesised that plyometric training duration of 6-7 weeks was too short to improve muscular power in some elite male athletes, due to a high training level and reduced adaptive capacity. A small positive training effect of plyometrics could be observed after only 6 weeks of training (Stojanović et al., 2016). Our participants were not elite, but competed at a national and regional level and significant improvements were frequently reported in comparable populations, although the training periods exceeded 8 weeks (Slimani et al., 2016). Next, plyometric training at a lower intensity or without some progressive overloads appears to be a less effective strategy than moderately high and progressive training, respectively. The training loads in the PLYO and CON groups were both maintained, so the stimulus for adaptation was potentially reduced and/or an interference effect occurred, due to concurrent endurance training (Davitt et al., 2014; García-Pallarés and Izquierdo, 2011). Some authors have reported that, for optimising maximal strength enhancement, the combination of training modalities (i.e., plyometrics and high-intensity resistance training) is needed (De Villarreal et al., 2010). In our study, jump training was executed in one mode. Previously, it was shown that a combination of plyometric drills was more effective than single plyometric drills (e.g., DJ, CMJ) (Ramírez-Campillo et al., 2015). Furthermore, a period of 10 weeks or more (more than 20 sessions of plyometric training in total) has been suggested to maximize the probability of obtaining significant performance improvements in athletes (Slimani et al., 2016). Therefore, the period of training tested in this work seems to be too short to elicit such gains.

Sprint performance

A recent meta-analysis (Slimani et al., 2016) highlighted a trend towards decreasing sprint times with plyometric training. In our study, we did not find significant changes in first cycle sprint performance, when measured as absolute or relative peak power, after training in either the PLYO or CON group. Similarly, Herrero et al. (2006) reported no significant gains in 20-m sprint times except when 4 weeks of plyometric training were combined with electromyostimulation. No significant differences were also observed in 5-m sprint and agility performances after a 9-week mid-season training programme supplemented with plyometric exercises (Brito et al., 2014). Many papers have reported statistically significant and positive effects of a plyometric programme on sprint performance (Arazi and Asadi, 2011; Slimani et al., 2016; Stojanović et al., 2016). In contrast, no changes were observed in selected studies. Sprint running performance did not change after 4-week plyometric training conducted on grass in 18 amateur, adult soccer players (Impellizzeri et al., 2008) as well as after 6-week depth jump (DJ) or countermovement jump (CMJ) plyometric training in semi-professional soccer players (Thomas et al., 2009).

RSA

There are only few studies investigating the effects of plyometric training on RSA in team-sport athletes. Hammami et al. (2016) revealed no significant difference in RSA variables with eight-week plyometric training incorporated into a standard soccer conditioning regimen. They found significant improvements in repeated running sprint performance in youth soccer players, but it was not more effective than traditional strength training (Hammami et al., 2016). In another study conducted on handball players, Hermassi et al. (2014) examined the effects of eight weeks of lower-limb plyometric training on shuttle running performance. They found that biweekly plyometric training improved several aspects of performance. However, no interaction effect was found between the groups performing standard training or standard training supplemented with plyometric exercises (50–100 ground contacts per session). In our study, we did not observe a significant increase in average peak power across five repetitions of all-out sprinting. The RSA scores tended to improve, but the changes did not reach statistical significance (p = 0.06). Interestingly, we noted an improvement in the fatigue index and maximal power in the last sprint repetition, but there were no significant differences between the treatment groups (p > 0.05).

In a previous investigation on elite youth soccer players, Buchheit el al. (2010) observed that repeated shuttle sprint training (10 weeks) improved RSA results more than explosive strength training. One reason for the lack of training-induced change herein could be poor movement specificity and lack of transfer into functional exercise. Also, training to improve sprinting power is not usually the main focus of handball practice during the pre-season phase, where emphasis is placed on the improvement of endurance and general strength.

VO_{2max}

The results of our study showed that plyometric training had no detrimental effect on endurance, or that an athlete can at least maintain a certain level of aerobic endurance while incorporating plyometric training in their regular programme. For coaches it is important whether aerobic capacity is negatively affected when handball training is performed concurrently with additional plyometric exercises. The results of our study show that the additional physiological stimulus provided by plyometric jump training was insufficient to elicit changes in cardiovascular variables in this 5-week period. The effects of a six-week plyometric training programme on distance running performance in 17 male subjects was examined by Spurrs et al. (2003). Plyometric training improved the subjects' 3 km time trial performance by 1.6%, but no significant changes in VO_{2max} or the lactate threshold in the experimental group were found. Therefore, it was speculated that the improved performance during the time trial was due to the improvement in running economy. We are not able to confirm this effect. The absence of VO2max improvement could suggest that the duration of the training program and/or the training stimulus was insufficient to generate an improvement. This study demonstrated that although the intervention protocols did not appear to positively influence VO_{2max}, they also did not hinder aerobic capacity. However, despite the lack of influence on VO_{2max}, we found a significant improvement in leg power generated at the anaerobic threshold, similar in both groups, which could be evaluated as a positive effect of training independent of the kind of additional jumping/plyometric exercises. The other studies demonstrated that plyometric training could be successfully employed to improve running speed, running economy and selected upper and lower body strength and power measures (Arazi et al., 2012; Saunders et al., 2006). All of these fitness components are important for the majority of sports, albeit to varying degrees. Most studies, however, suggest that plyometric training may enhance overall athletic performance.

Most of the studies on the effects of plyometric training have demonstrated improvements in vertical jump performance. In contrast, a number of authors failed to report significant positive effects of plyometric training on vertical jump height, and some of them even reported negative effects (Luebbers et al., 2003; Markovic, 2007b). Thus, at present, definitive conclusions regarding the effects of PT on vertical jump performance cannot be drawn. The factors that may be responsible for the discrepancy among the results of this and other studies concern the training programme design (type of exercises used, training duration, training frequency, volume and intensity of training), subject characteristics (age, gender, fitness level) and methods of testing physical performance. Moreover, the effects of PT may differ depending on sports activity and familiarity with PT, and also the combination of unilateral and bilateral jump drills seems more advantageous to induce significant sprint performance improvements during high-intensity short-term plyometric training (Slimani et al., 2016). Plyometric exercise mainly affected the fast-twitch muscle fibres, damaging both the sarcolemma and the sarcomere at the site of the Z-disk. Thus, coaches should avoid prescribing high-volume plyometric exercise bouts within short succession or after other forms of high-intensity exercise that are known to stress the fast-twitch muscle fibres, so that athletes have sufficient time to regenerate damaged fibres (Macaluso et al., 2012). Regarding neuromuscular performance, plyometric exercises can even be performed after strength-power training on the same day if a minimum rest period of 3 h is provided (Hartmann et al., 2015). An adequate progressive increase in the plyometric training volume-based load should result in greater performance adaptations in explosive movements and aerobic endurance (Ramírez-Campillo et al., 2015). According to Potach and Chu (2000), plyometric programmes ranging between six and ten weeks, with training sessions two to four times per week, are sufficient to elicit positive training effects. Therefore, the number of sessions used in this study seems to be insufficient to obtain the necessary results. It could be speculated that the detraining period in the examined teams was too long and athletes did not present sufficient strength levels to perform movements like plyometrics. This situation could have delayed the adaptation period of the subjects when the plyometric intervention started, resulting in a much slower progression in exercise performance. Contrary to that, it was shown that a training programme of two weeks with three sessions per week including high-intensity plyometric exercises (between 180 and 250 jumps per session) in well-trained athletes can be recommended as a short-term strategy that will optimize the likelihood of obtaining significant improvements in explosive power and sprint velocity performance (Maćkała and Fostiak, 2015).

Limitations

There are some limitations of this study. The cycle ergometer test has been previously widely used to evaluate adaptation to physical exercise training, but does not involve the stretch-shortening cycle, which is widely represented in the plyometric training programme. This could limit the possibility of detecting changes in sprint performance. In addition, sprint cycling is somewhat unfamiliar to handball players. However, the examined athletes were previously frequently tested in different anaerobic cycling tests. It should be acknowledged that our subjects were limited to one category of youth male handball players, and these observations should be extended to the female population with caution. Furthermore, more investigations are needed with different intensities and volumes of plyometric training to determine the optimum load for this form of pre-season training. It should be noted that an on-court (including plyometric actions) training programme supplemented with plyometric strength training may produce excessive physical loads for the adaptive capabilities of young athletes and, with the lack of a supercompensation phase, it could have a negative influence on subsequent measurements. Another limitation is the lack of an additional control group practising handball without additional jumping or plyometric drills – this could help to determine if there was any interference effect of concurrent training on endurance and explosive strength performance.

Practical implications

The study showed that plyometric training and jump training added to standard handball training did not differ significantly in enhancing submaximal aerobic and anaerobic performance of young handball players. Thus, coaches may have the possibility of alternating between these methods to maintain performance (Gottlieb et al., 2014). It could be speculated that the pre-season training period should be longer than 5 weeks to produce adequate training-induced changes in aerobic and anaerobic capacity.

Conclusions

A 5-week standard training programme supplemented with only 15 sessions of plyometric exercises seems too short to gain significant and concurrent improvements in jumping, repeated sprint ability and aerobic capacity. With the pattern of standard handball training supplemented with plyometric training that we adopted, and perhaps because participants were in good initial physical condition, only aerobic capacity and indices of fatigue in anaerobic exercise were improved, whereas indices of maximal aerobic and anaerobic capacity remained unchanged. Further studies are needed to determine how to manipulate training volume and modality during the pre-season period to maximize performance in young team sport athletes.

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