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Resistance, Plyometrics and Combined Training in Children and Adolescents' Volleyball Players: A Review Study

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Review Article

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ABSTRACT

The health enhancing properties of physical activity are evidence-based and widely accepted for children and adolescents. Today many children and adolescents are engaged in specific sports and that causes great attention of coaches to use safe and appropriate methods. Volleyball is of the most popular sports among this group. Because of powerful and explosive movements as well as high-repeated jumps and landings suitable training program should be considered to improve performance and prevent injuries in children and adolescents. The aim of this study is to review studies about resistance training, plyometric training and combined training and effects of these training methods on physical fitness in children and adolescents. Our investigation begun with search engine and scientific databases with keywords in three section; title and abstracts, articles and finally references. Primary research articles were selected if they (a) included outcomes of a resistance, plyometric and combined training intervention, (b) included volleyball training protocols, (c) included children and adolescents 8–18 years of age. Review show that resistance training would enhance physical performance as well as plyometrics training. Improvements in motor performance skills, such as jumping, are widely stated as indicators of improvements in sporting performance. Although combination of resistance and plyometrics is a useful methods for jumping improvement little is available about the effects on children and adolescents.

Keywords: Volleyball; resistance training; plyometrics; adolescents; children; jumping.

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1. INTRODUCTION

Participation of children and adolescent in at least 60 minutes of moderate to heavy intensity physical activities which are developmentally appropriate is recommended [1]. Studies have mentioned great benefits of physical activity in children, including control of body weight by increasing energy expenditure, avoiding developing adult obesity, reducing the risk of developing premature cardiovascular disease, type-2 diabetes, metabolic syndrome, some site specific cancers, bone formation and remodeling, reducing depression and anxiety, enhancing mood, self-esteem and quality of life, reducing rule-breaking behavior and improving academic performance [2,3,4]. Childhood provides a great opportunity to influence attitudes and participation levels positively toward physical activity. Significant effects on height, balance, flexibility and fat percentage as well as self confidence and social skills enhancements have been reported following regular physical activity in 9-10 years children [5]. Along with increasing rate of children and adolescents participation in organized sport all around the world over the past 50 years, the trend has been for children to become involved in competitive sports programs as early as age 5 years old [6]. Easy to play, low risk of injuries because of non-contact nature [7,8] have caused volleyball more popular among all people especially children and adolescents [9]. For children aged 9–13 years who demonstrate an interest in the game and wish to play it competitively, a developmentally appropriate version of volleyball has been invented. Called “mini-volleyball,” the game is tailored to preadolescent athletes and permits them to learn the essential elements and skills of the sport in a safe environment [10]. Mini-volleyball, as a sport of power and quickness, requires a detailed skill, including physical, technical, mental and tactical aspects [11] and thus in order to maximize performance, volleyball players should follow a conditioning and training program that develops volleyball-specific neuromuscular abilities [12]. Peak conditioning is essential to achieving optimal performance and needs a systematic approach using an appropriate training methodology such as resistance training (RT), plyometric training (PT) and some other types, even for beginners and adolescents engaged in volleyball. Although there are many potential benefits from such a programmatic approach to children and adolescents sports, a number of potential drawbacks exist as well as a dramatic increase in the incidence of pediatric injuries that has resulted by inappropriate training programs. Thus it seems that designing suitable and appropriate training programs for children and adolescents especially when participating in a systematic and organized sport such as mini-volleyball is of the great concerns for coaches and scientists. The purpose of this systematic review was to examine the extent and quality of the current research literature, to evaluate the efficacy and safety of resistance, plyometric and complex training for improving motor performance in young children, and to determine if this type of training could be used to improve the motor skills of children and adolescents participating in organized sports such as mini-volleyball.

2. MATERIALS AND METHODS

To obtain relevant literature on different types of training, abstracts and citations were identified through a search using the Sciencdirect and Proquest search engines from March 2013 up to September 2013. Articles published in English and in peer reviewed journals were considered for the review. The initial search focused on finding literature using physical activity in children. Search terms included ‘‘physical activity for children,’’ ‘‘children and adolescents sports,’’ ‘‘fun physical activity for children and adolescents,’’ ‘‘exercise for children’’ in various combinations. Next search continued by adding new keywords focused on volleyball and different training programs. The following search terms were used in various combinations to identify primary research articles including ‘‘children and adolescents training programs,’’ ‘‘children jumping performance,’’ ‘‘jump training,’’ ‘‘resistance training for children,’’ ‘‘plyometric for children and adolescents,’’ ‘‘resistance and plyometric training for volleyball,’’ ‘‘improving jumping performance in children volleyball players,’’ ‘‘jump training,’’ ‘‘mini volleyball jumping ,’’ and ‘‘sport performance.’’ The earliest randomized control trial to describe motor outcomes of training in children was published in 1971. Therefore, no year restriction was placed on the search. In the first stage of screening, titles and abstracts of identified articles were checked for relevance. In the second stage, full-text articles were retrieved and considered for inclusion. In the final stage, the reference lists of retrieved full-text articles were searched for additional articles. Primary research articles were selected if they (a) participants were aged 8–18 years and selected from a sports or athletic population (defined as participants who engaged in organized sports training); (b) study involved the evaluation of a resistance, plyometric and combined training with an aim to improve sports performance where explosive power is necessary for success; (c) study was a randomized controlled trial or single group pre-test posttest design with respect to jumping performance improvement. Articles that met the 3 inclusion criteria were chosen for the final review. 162 titles were found and articles including training procedure for rehabilitation and for children and adolescents with impairment such as poor motor performance were omitted.

3. DISCUSSION

3.1 Jumping in Volleyball

The ability to jump high, quickly and explosively is essential to most of the volleyball’s skills, including spiking, blocking, jump serving, and even setting in mini-volleyball [9,28,29,30]. Thus, it is common for mini-volleyball athletes to place considerable emphasis on jumping training and follow an appropriate program to improve jumping ability and neuromuscular related components [12].

According to the importance of vertical jumping in volleyball, jumping performance tests are frequently studied for evaluation of performance and measurements of volleyball player’s physical fitness. Sattler et al. [31] determined the reliability and factorial validity of 2 volleyball-specific jumping tests, the block jump (BJ) test and the attack jump (AJ) test, relative to 2 frequently used and systematically validated jumping tests, the countermovement jump (CMVJ) test and the squat jump (SJ) test.

It would be useful to mention that in SJ the subject starts from a stationary semi-squatting position, or pauses at the lower level of the squat before jumping upwards. This removes the factor of the stretch-shortening cycle (pre-stretching of muscles) but in CMVJ there is bending of the knees immediately prior to the jump thus activates the stretch-shortening cycle in the muscles, resulting in greater power production in the legs [31].

Jumping performance is dependent on strength, power and anthropometric parameters and is known as special index for success in volleyball players. Ziv & Lidor found that jumping records of elite male and female volleyball players is significantly higher comparing to recreational volleyball players, mainly because of participating in plyometric training sessions and following conditioning programs during the competitions. Moreover, vertical jump as well as anthropometric parameters could be considered as the main aspects of differences between elite and non elite volleyball players [32]. Sheppard & Newton showed that elite male volleyball players can improve leanness and power, which contribute to improvements in vertical jump [33] and Grgantov et al. [34] showed that throwing and spiking speed from the ground had the largest influence on player quality, followed by volleyball-specific jumping and nonspecific jumping as well as sprinting. Great attention is placed on jumping enhancement training methods. Squat jump and countermovement jump are of the most common jumping training which is used widely among volleyball players. Sheppard et al. examined the potential strength, power, and anthropometric contributors to vertical jump performances that are considered specific to volleyball success: the spike jump (SPJ) and (CMVJ) [35]. In a similar study, Sheppard et al. [36] observed significant improvements in CMVJ with increased peak force in the unloaded and loaded jump and greater relative power and peak velocity in the loaded jump squat. Results of these two studies show that in an elite population of volleyball players, stretch-shortening cycle performance and the ability to tolerate high stretch loads, as in the depth jump, are critical to improving jumping performance [35,36].

Padulo et al. [37] investigated the muscular activity (EMG) of the biceps femoris (BF) in different phases (concentric vs. eccentric) of a CMJ, SJ and the Braking Phase (BP) of a landing task and found significantly lower BF activation in the concentric and eccentric portions of the CMJ compared to the BP and SJ, suggesting that the CMJ relies on a greater contribution of elastic tissues during the concentric and eccentric portions of the movement and thus requires less muscle activation of the BF.

Concentration on appropriate training methods of jumping not only cause better performance in games but also may reduce risks of injuries. Perhaps because of deceleration or landing task suggesting negative work, jumping may cause injuries in lower extremity especially Hamstrings injuries [12]. Coaches should decide what physical exercise should be used to improve athletic performance most efficiently. From this point of view, selecting exercises that simultaneously act positively on more than one performance variable seems an interesting choice [38]. There are many kinds of training suggested for jumping improvement especially for volleyball players during competitions and even in off season. A general conditioning and hypertrophy training along with specific volleyball conditioning is necessary in the preseason period for the development of the lower-body strength, agility and speed performance in volleyball players. Trajković et al. [39] found significant improvement in speed and no significant differences for lower-body muscular power (vertical-jump height, spike-jump height, and Block jump) as well as agility following a 6-week skill-based conditioning training program in male competitive volleyball players during pre competition season. Marques et al. found that elite female volleyball players can improve strength and power during the competition season by implementing a well-designed training program, including both resistance and plyometric exercises [40]. Barnes et al. [41] concluded that agility training is of the effective types of training which may result in vertical jump improvement. It means that volleyball players with greater countermovement performance also have quicker agility times. Granacher et al. [42] showed that balance training results significant improvement in postural control, increased jumping height, and enhanced rate of force development of the leg extensors. Newton et al. studied the effectiveness of ballistic resistance training for improving vertical jump performance in elite jump athletes [43]. Malatesta et al. [44] found that 4-week Electromyostimulation (EMS) training program would be effective on the vertical jump, enabling the central nervous system to optimize the control to neuromuscular properties.

Investigations related to children and adolescents' training programs and volleyball trainings protocols are mentioned at Tables 1 and 2, respectively. Powerful jumping and forceful movement introduce volleyball a sport with specific skills which can improve and enhance physical fitness values especially in children and adolescents [14], but unfortunately little attention is paid to it. Thus investigation of different type of training protocols on jumping performance of volleyball players, especially in children and adolescents, as mini-volleyball players, seems to be a challenging and needs a lot concern.

Table 1. Investigations related to children and adolescents training programs

Author source	Purpose	Subjects	Age (Years old)	Results
Vassil & Bazanov [13]	To investigate effect of plyometric training program on junior volleyball players	Male (n=12) Female (n=9)	17.0±1.25 14.1±1.80	Medicine ball throws↑(p<0.01) vertical jumps to the maximal height in 10 seconds↑(p<0.01)
Dorak et al. [5]	To examine effects of 8 weeks of sports activities on some parameters in children	Experimental (Male: n=10, Female: n=12) Control (Male: n=8, Female: n=12)	9-10	Height ↑(p<0.05) Weight ↑(p<0.05) Flexibility ↑(p<0.05) Balance ↑(p<0.05) Fat percentage ↓(p<0.05)
Sozen [14]	To investigate effect of volleyball training on the physical fitness of high school students	Experimental (Male: n=17, Female: n=14) Control (Male: n=17 & Female: n=14)	14-16	Sit ups ↑(p<0.05) Balance ↑(p<0.05) 10 x 5m shuttle-run ↓(p<0.05) Sit-and-reach ↑(p<0.05)
Martínez-López et al. [15]	To examine the effects of eight-week plyometric (PT) and neuromuscular Electrostimulation (EMS) on jump height in young athletes	Male (n=51) Female (n=47)	17.91±1.42	combination of 150Hz EMS + PT: jump height ↑(p<0.05) combination of ≤ 85Hz EMS + PT: No sig. difference in jump height
Rubley et al. [16]	To measure the effects of low frequency, low impact plyometric training on vertical jump and kicking distance in female adolescent soccer players	Female Experimental (n=10) Control (n=6)	13±4	No sig differnces over time in No diff between groups pretest or 7 wks post-test jump height, kicking distance, at 14 wks in training group ↑(p<0.05)
Meylan & Malatesta [17]	To study effects of plyometric training within soccer practice on explosive actions of young players	Experimental (n=14) Control (n=11)	13.3±0.6 13.1±0.6	10m sprint time ↓(p<0.05) Agility ↓(p<0.05) Jump height ↑(p<0.05)

Santos & Janiera [18]	To Study the effects of complex training on explosive strength in male basketball players	Experimental (n=15) Control (n=10)	14-15	squat jump ↑(p<0.05) countermovement jump↑(p<0.05) depth jump ↑(p<0.05) mechanical power ↑(p<0.05) medicine ball throw ↑(p<0.05)
Faigenbaum et al. [19]	To compare the effects of six Week combined plyometric and resistance and resistance training on fitness performance in boys	Plyometric and resistance training (PRT, n=13) Resistance training (RT, n=14)	12-15	PRT comparing to RT: long jump ↑(p<0.05) Medicine ball toss ↑(p<0.05) Agility ↓(p<0.05) shuttle run time ↓(p<0.05)
Kotzamanidis [20]	To investigate the effect of plyometric training on running velocity and squat jump in boys	Experimental (n=15) Control (n=15)	11.1±0.5 10.9±0.7	Squat jump ↑(p<0.05) Velocity 0-30m, 10-20m, 20-30m ↑(p<0.05)
Faigenbaum et al. [21]	To compare the effects of 1 and 2 days per week of strength training on upper body strength, lower body strength, and motor performance ability in children	Female (n= 21) Male (n=34) Control (n=13) 1 Day/Week (n=22) 2 Day/Week (n=20)	7.1 12.3	2 Day/Week: Chest press strength: ↑(p<0.05) 1 Day/Week & 2 Day/Week: Leg press strength : ↑(p<0.05) No Sig. Differences between parameters of 1 Day/Week & 2 Day/Week
Faigenbaum et al. [22]	To Study the effects of different resistance training protocols on upper-body strength and endurance development in children	Heavy load chest press (HL, n = 15) Moderate load chest press (ML, n = 16) Heavy load chest press +Medicine ball chest passes (CX, n = 12); Medicine ball chest passes (MB, n = 11) Control (n=12)	8.1±1.6	ML & CX: 1RM chest press strength ↑(p<0.05) Local muscle endurance ↑(p<0.05)

Diallo et al. [23]	To investigate effects of plyometric training followed by a reduced training program on physical performance in adolescents	Experimental (n=10) Control (n=10)	12-13	Maximal cycling power ↑($p<0.01$) countermovement jump ↑($p<0.01$) squat jump ↑($p<0.01$) multiple 5 bounds ↑($p<0.05$) repeated rebound jump for 15 seconds ↑($p<0.01$)
Witzke & Snow [24]	To investigate effects of plyometric jump training on bone mass in adolescent girls	Experimental (n=25) Control (n=28)	14.6±0.5	bone mass↑($p<0.01$) knee extensor strength ↑($p<0.05$) balance ↑($p<0.05$)
Faigenbaum et al. [25]	To investigate effects of different resistance training protocols on muscular strength and endurance development in children	Male (n=32) Female (n=11)	11.8 5.2	Leg extension muscular endurance ↑($p<0.05$) Chest 1-RM strength ↑($p<0.05$)
Morris et al. [26]	To investigate ten-Month exercise in pre-menarcheal girls	Experimental (n=71)	9-10	lean mass ↑($p<0.05$) body fat ↓($p<0.05$) shoulder, knee and grip strength↑($p<0.05$) Total body, lumbar spine, proximal femur, femoral neck bone mineral density ↑($p<0.05$)
Lillegard et al. [27]	To study efficacy of strength training in prepubescent to early post-pubescent males and females	Experimental (n=52) Control (n=39)	8-10	Increased body segment girths Decreased skinfold thickness Flexibility ↑($p<0.05$)

Table 2. Investigations related to volleyball trainings protocols

Researchers	Purpose	Subjects and age	Results
Grantov et al. [34]	To Identify explosive power factors as predictors of player quality in young volleyball players	Female (n=56)	Identified factors as a good predictors of player quality in young female volleyball players: -volleyball-specific jumping - nonspecific jumping and sprinting - throwing explosive power - volleyball-specific throwing and spiking speed from the ground
Voelzke et al. [49]	To compare the impact of short term training with resistance plus plyometric training (RT+P) or Electromyostimulation plus plyometric training (EMS+P) on explosive force production in elite volleyball players.	EMS+P training group (n =8)(23.8±2.6) RT+P training group (n = 8)(26.0±7.0)	- RT+P training: Squat jump, three step reach height ↑($p<0.05$) - EMS+P training group: Countermovement jump, depth jump, three step reach height ↑($p<0.05$) Fifteen m lateral sprint and after 5 m and 10 m of the fifteen m straight sprint ↓($p<0.05$) - Comparison of training-induced changes between the two intervention groups: Sig. Differences of squat jump in favor of RT+P and for the fifteen m straight sprint after 5 m in favor of EMS+P.
Vassil & Bazanov [13]	To investigate effect of plyometric training program on junior volley ball players	Male: (n=12) (17.0±1.25 yr) Female: (n=9)(14.1±1.80)	- Medicine ball throws↑($p<0.01$) - vertical jumps to the maximal height in 10 seconds↑($p<0.01$)
Fattahi et al. [9]	To study relationship between anthropometric parameters with vertical jump in elite volleyball players	Male (n=40) (27.93±3.92 yr)	- Sig. relationship between vertical jumps with shank length, maximum calf circumference, foot length
Sattler et al. [31]	To investigate effect of volleyball training on the physical fitness of high school students	Male (n=95)	- The highest reliability for the specific jumping tests: block jump (BJ) and attack jump (AJ) test, relative to 2 frequently used and systematically validated jumping tests, the countermovement jump test and the squat jump test

Rezaeimanesh & Amiri [50]	To study effect of a 6 week isotonic training period on lower body muscle EMG changes in volleyball players	n=15 (18.4-23.7 yr)	- EMG of the biceps femoris while performing the Squat Movement ↑($p<0.05$) - No sig. change in EMG for the biceps femoris in the vertical jump
Sozen [14]	To investigate effect of volleyball training on the physical fitness of high school students	Male (n=34) Female (n=28) (14-16 yr)	Sit ups ↑($p<0.05$) Balance ↑($p<0.05$) 10 x 5m shuttle-run ↓($p<0.05$) Sit-and-reach ↑($p<0.05$)
Sharma et al. [51]	To establish the effects of core strengthening exercise program on trunk instability in response to vertical jump performances and static balance variables in volleyball players	Experimental : (Male, n=10, Female n=10) Control: (Male, n=10, Female n=10)	- After nine weeks of core stabilization training: - trunk stability ↑($P<0.001$) - block jump ↑($P<0.01$)
Ziv & Lidor [32]	To study vertical jump in female and male volleyball players	A review of observational and experimental studies	- players of better performing teams have higher VJ values - strength and conditioning programs that emphasize plyometric training can increase jumping performance - It is important to continue conditioning sessions throughout the season in order to maintain jumping performance
Trajkovic et al. [39]	To Study effects of 6 weeks of preseason skill-based conditioning on physical performance in volleyball players	Male (n=16)(22.3 ± 3.7 yr)	- 5 and 10-m speed ↑($p<0.05$) - No sig. differences for lower-body muscular power (vertical-jump height, spike-jump height, and SBJ) and agility between pre and post
Sheppard and Newton [33]	To study Long-term training adaptations in elite volleyball players	Male (n=14)(23.0 ± 4.1 yr)	- Sum of 7 Skinfolds ↓($p<0.05$) - large magnitude changes in Depth jump, Spike jump and squat jump +50% of body weight
Sheppard et al. [36]	To study twelve-month training-induced changes in elite international volleyball players	Male (n=20)	Spike jump↑($p<0.05$) relative power ↑($p<0.05$) peak force↑($p<0.05$) peak velocity↑($p<0.05$) - improved depth-jumping ability

Sheppard et al. [35]	To Study relative importance of strength, power, and anthropometric measures to jump performance of elite volleyball players	seven best subjects and the seven worst athletes on the Countermovement jump (CMVJ) and spike jump (SPJ) tests (n=14)	- moderate correlations between the 1RM measures and both CMVJ and SPJ - strong correlations depth jump performance and SPJ and CMVJ
Marques et al. [40]	To study changes in strength and power performance in elite senior professional volleyball players during the in-season	Female (n=10)	- Strength in bench press and parallel squat ↑($p<0.0001$) - Distance in the overhead medicine ball ↑($p<0.01$) - Increased unloaded and loaded CMJ height
Barnes et al. [41]	To investigate relationship of jumping and agility performance in female volleyball athletes	Female in National Collegiate Athletic Association Division I (n=9), II (n=10),and III (n=9)	- Sig. greater jumping height between Division I and Division II & III - Center of mass: a sig. predictor for agility performance
Martel et al. [52]	To examine the effects of aquatic plyometric training on Vertical jump and muscular strength in volleyball players	Female (n=19) (15±1 yr)	After 4 weeks for both aquatic and control group: - Vertical jump and peak torque during knee extension and flexion at 60 and 180 degrees ↑($p<0.05$)
Malatesta et al. [44]	To study effects of Electromyostimulation (EMS) training and volleyball practice on jumping ability	Experimental (n=12)	- No sig. changes after EMS training for squat jump and counter movement jump - jump height, Ten days after the end of EMS training ↑($p<0.05$)
Newton et al. [53]	To investigate effects of ballistic training on preseason preparation of elite volleyball players	Experimental (n=8) Control (n=8) (19.2±2 yr)	- standing vertical jump and reach (SJR) and jump and reach from a three-step approach (AJR) ↑($p<0.05$)

3.2 Resistance Training

Resistance training (RT) for children and adolescents has attracted increased interest as a means to improve health and performance-related fitness components [45]. RT is defined as a specialized form of conditioning involving the progressive use of a wide range of resistive loads and a variety of training modalities designed to enhance health, fitness, sports and not sport [21,46]. In early childhood following appropriate nutrition programs, physical activities, including resistance training, would be effective in growth [47].

Some authors observed positive effects of heavy intensity resistance training on bone mineral density in children and adolescents [26,48]. Although peak bone mass is strongly influenced by genetics, this particular health benefit may play a role in the prevention of youth sports injuries and may be especially important for young women who are at increased risk for osteopenia or osteoporosis. Childhood may be an opportune time for the bone modeling and remodeling process to respond to the mechanical loading of high impact physical activities [38].

Although the potential for youth having a favorable influence on bone mineral density is encouraging, the strength training program needs to be carefully developed and monitored because too much exercise may result in bone loss and increased susceptibility to fractures [54]. Of the great concerns about children and adolescents in early investigations was the potential of injuries in growth cartilages, epiphysis plates and statural growth disturbance while performing RT [55]. This myth seems to have been fueled by an earlier report suggested that children who performed heavy labor experienced damage to their epiphyseal plates, which resulted in significant decreases in other causative factors, however, such as poor nutrition, were not accounted for in this study [56]. Some investigations reported fractures in youth weight lifters [57,58,59] but the main reason would be perhaps poor technique and very heavy load. Current observations indicate no evidence of a decrease in stature in children and adolescents who participate in well-designed youth strength training program [38,60,61,62]. It is documented that children and adolescents are less prone to fracture injuries because the solid and tight nature of the bone structure against shearing stresses [63]. Malina et al. and Ratel showed that resistance training programs did not influence growth in height and weight of pre- and early-adolescent youth as well as anthropometric parameters as the most valuable factors in talent identification [64,65], thus participation of children from the beginning of 6 in RT programs seems to be beneficial [66,67]. Coaches and trainers are advised to be aware of overuse injuries of soft tissues [57,68]. In spite of these recommendations, it is well established that as soon as children and adolescents are prepared to participate in sports competitions, resistance training should be considered as an important part of their conditioning. Although the potential for adolescents to increase their muscular strength in response to a training program is well established [25,46,54,69] the traditional belief was that training-induced strength gains during preadolescence were not possible because of insufficient levels of circulating androgens and hormones [70,71]. Despite that, methodological limitations, such as a short study duration, a low training volume (sets X repetitions X load), and, in some cases, a lack of adequate control of growth or learning, may have influenced the results. Vrijens et al. [70] concluded strength development was closely related to sexual maturation, and that strength training could be effective only in the post-pubescent age. More recent investigations using higher intensities and greater volume of training are now challenging this idea. Pfeiffer and Francis (1986) noted significant strength gains in a group of preadolescent boys participated in RT for 9 weeks [72], Servedio et al. and Sewall & Michelli reported significant gains in isokinetic shoulder flexion following 8 weeks of resistance training [73,74]. Weltman et al.

[67] reported strength gain of 18% to 36% following 14 weeks RT. Ramsay et al. [75] concluded that 20 weeks of strength training resulted in significant gains in bench-press strength (35%), leg press strength (22%), and other strength measures in preadolescent boys. Faigenbaum et al. [54] reported to 74% improvements after 8 weeks of RT in preadolescent boys and girls. Recent data from Lillegard et al. [27] who studied preadolescent to early post-pubescent males and females provide additional evidence that training-induced strength gains are possible in young weight trainers. It seems that changes in motor unit activation, motor unit coordination, motor unit recruitment and firing were responsible, at least in part, for the observed strength gains [60,62,76]. Reports suggest also sports-conditioning drills could be effective for strength enhancement in young athletes. Clarke et al. reported a significant increase in isometric strength and performance tests after 3 months of wrestling training in 7- to 9-year-old boys [77]. A variety of training sets and repetition, from 1 set of 10 repetitions [78] to 5 sets of 15 repetitions [79] can provide adequate stimuli for strength improvement in children and adolescents. The degree of variability in observed strength gains, form 30% to 50% following short term (8-12 weeks) to 74%, may be related to several factors, including the program design, quality of instruction, specificity of testing and training, whether the researchers accounted for the learning effect, and the participants' background level of physical activity. It could be mentioned that in designing RT programs for children and adolescents the higher relative strength comparing to adults should be taken into consideration [60]. Safety and appropriate supervision is of the great concerns of coaches in RT programs in children and adolescents. It is well-documented that this training mode is a safe and effective means of developing maximal strength, maximal power output and athletic performance in youth, provided that exercises are performed with appropriate supervision and precautions [38,46,62,64,65,76,80,81,82]. Malina et al. reported significant increases in muscular strength in children and adolescents after 2 to 3 sessions of RT programs in 8 to 12 weeks [64]. Daily Participation of children and adolescents in RT programs is necessary [46] and is advised because of muscular strength and physical fitness enhancement such as vertical jump and Wingate test [65]. Strength training during childhood and adolescence may provide not only the foundation for dramatic strength gains during adulthood, but, as children and adolescents gain self-confidence in their physical abilities [45], they may be more likely to experience success and less likely to drop out of sports [62]. Prevention of injuries is known as the other main advantages of RT programs for children and adolescents engaged with professional sports [22,34,75]. A proper RT program is defined by frequency, mode (type of resistance), intensity, and duration of the training program. Although regular participation in a progressive resistance training program can increase children's muscular strength and endurance, but the most effective exercise prescription regarding the number of repetitions remains questionable. Faigenbaum et al. [25] compared the effects of a low repetition-heavy load resistance training program and a high repetition-moderate load resistance training program for the development of muscular strength and muscular endurance in children and concluded that muscular strength and muscular endurance can be improved during the childhood years and favor the prescription of higher repetition-moderate load resistance training programs during the initial adaptation period. In a similar study Faigenbaum et al. examined the effects of 4 different resistance training protocols on upper-body strength and local muscle endurance development in children. In terms of enhancing the upper-body strength and local muscle endurance of untrained children, findings favor the prescription of higher-repetition training protocols during the initial adaptation period [22].

According to Kiener et al. [83] an early-established strength training regimen brings many benefit young athletes, especially those engaged in competitive sports. Strength training also leads to improve athletic performance. Some researchers believe that muscular strength can be improved during the childhood years and favor a training frequency of twice per week for children participating in an introductory strength training program. Faigenbaum et al. concluded that two days per week of strength training could enhance muscular strength and motor performance ability more than one day per week in children and adolescents [21] in agreement with the investigation of Stickers et al. [61]. A 30% increase in strength is typically observed after appropriately designed and supervised short-term RT programs undertaken by children and adolescents [46]. Detraining is another concern of investigators and decrease in strength of children and adolescents have been reported because of detraining (between 8 to 12 weeks) [25,74,84]. Even one day per week training program was not enough to maintain training-induced gains in preadolescent boys [84]. Conversely, Derenne et al. [85] noted that strength training once per week was as effective as twice per week in maintaining training-induced strength gains in young baseball players (age 13.2 years) [85]. It seems changes in neuromuscular functioning (and possibly a loss of motor coordination) would be at least partly responsible for the detraining response observed in children.

Numerous beneficial effects have been reported on muscular strength [46,62,64], prevention and rehabilitation of injuries, long term health, cardiovascular fitness, body composition, bone mineral density, blood lipid profiles and self-esteem, depression and mental health in children and adolescents while using RT [46,62,76]. Besides the positive effects of RT in children and adolescents physical fitness and strength factors, RT is reported to have great advantages in sport performance skills [46,62,76,86]. Explosive muscle power and rate of force production are fundamental elements in many sports [87,88]. Improvements in motor performance skills are also reported to contribute to increases in strength, for example, vertical jumps and sprint times, as a practical cost effective tool [87,89,90]. Witmer et al. [91] found that use of resistance exercises performed prior to a series of vertical jumps can result in improvements in performance. There does not seem to be any difference between men and women in the response to dynamic potentiating protocols. For many professional players and coaches deriving best results would be an optimal goal, depending on the nature of sport. For example, in explosive movement, such as jumping in volleyball, handball and basketball use of RT is advised. Hermassi et al. [92] showed that in-season biweekly RT can be recommended to elite male handball players as improving many measures of handball-related performance, such as jumping, without adverse effects upon the speed of movement. Newton et al. [53] supported the effectiveness of ballistic resistance training for improving vertical jump performance in elite jump through increased overall force output during jumping, and in particular increased rate of force. Sharma et al. [51] found that nine-week strategic core strengthening exercise program increases trunk stability and in turn improves block difference (vertical jump parameter) in volleyball players. Both physical performance and the associated physiological adaptations are linked to the intensity and number of repetitions performed [93]. Wolfe et al. [94] indicated that trained individuals performing multiple sets generated significantly greater increases in strength comparing to single-set programs and multiple-set programs are more effective. Rezaimanesh et al. [50] focused on the effect of a 6 week isotonic training period on lower body muscle EMG changes in university volleyball players and resulted that RT can increase the EMG of lower body muscles in athletes.

3.3 Plyometrics Training

Plyometrics is the main part of the most physical activities including running, jumping, hopping and throwing which is observed in children's' games. Plyometric training is an extremely successful method of transforming strength into power [12]. As with most types of exercise, plyometric exercises range from those that are easy to perform to those that are extremely difficult to perform. This permits the athlete to progress through a program of progressive overload in order to promote neuromuscular adaptation to the demands of training and, with that, improved sports performance. Plyometric training consists of exercises in which muscle is loaded eccentrically (lengthening activation) followed immediately by a concentric (shortening) activation [19]. Research has demonstrated that a muscle stretched prior to a shortening activation will contract forcefully and rapidly [95]. Plyometric action relies on the muscle stretch reflex, which is mediated by the muscle spindle located in the muscle belly. The main purpose of the stretch reflex is to monitor the degree of muscle stretch and prevent overstretching. A plyometric exercise such as a drop jump requires a quick, reactive body movement to attain the power required for the action. Plyometric training causes muscular and neural changes that facilitate and enhance the development of rapid and powerful movements. Eccentrically loading muscle stores potential energy within the series of elastic component of the muscle. Similar in concept to a loaded spring, when released during the subsequent concentric muscle activation, this energy augments that energy generated by the contractile apparatus of the muscle fibers [12]. Like any other training program, there are great concerns about the efficacy and safety of plyometric training for improving motor performance especially in children. Johnson et al. suggest that plyometric training is safe for children when parents provide consent, children agree to participate, and safety guidelines are built into the intervention, Plyometric training had a large effect on improving the ability to run and jump, also on the increasing kicking distance, balance, and agility. Twice a week program for 8-10 weeks beginning at 50-60 jumps a session and increasing exercise load weekly results in the largest changes in running and jumping performance in children [96]. In children who participated regularly in sports activities PT is suggested by means of skill improvements, especially for jumping. Kotzamanidis et al. suggest that Plyometric exercises can improve squat jump and running velocity in prepubertal boys. More specifically, this program selectively influenced the maximum velocity phase, but not the acceleration phase [20]. Diallo et al. [23] showed that short-term plyometric training programs increase athletic performances in prepubescent boys and these improvements were maintained over a period of reduced training. The short-term plyometric program had a beneficial impact on explosive actions, such as sprinting, change of direction, and jumping, which are important determinants of match-winning actions in soccer performance. Meylan et al. [17] revealed that plyometric program within the regular soccer practice improved explosive actions of young players compared to conventional soccer training only. Burgess et al. [97] determined the effect that plyometric and isometric training on tendon stiffness (K) and muscle output characteristics to compare any subsequent changes.

Of the challenging concerns about plyometric is the volume and intensity of the training program. Chelly et al. [98] showed that biweekly plyometric training of junior soccer players (including adapted hurdle and depth jumps) improved important components of athletic performance relative to the standard in-season training, thus such exercises are highly recommended as part of an annual soccer training program. Matavulj et al. [90] found that a limited amount of plyometric training could improve jumping performance in elite junior basketball players and this improvement could be partly related to an increase in F of the hip extensors and RFD of knee extensors. De Villarrea et al. [99] showed that short-term plyometric training using moderate training frequency and volume of jumps (2 days per week, 840 jumps) produces similar enhancements in jumping performance, but greater training efficiency compared with high jumping (4 days per week, 1680 jumps) training frequency. Vassil et al. [13] studied the efficiency of plyometric training program on youth volleyball players force capabilities in their usual training period during 16 week period and found reliable improvement in athlete's legs and arms speed force reliable improvement.

Some researchers have investigated effects of different Plyometric Programs on physical abilities various sports, mostly in football and basketball and they reported significant improvement [16,17,23,90,98,100]. Not only plyometric training would be effective skill performance but also study of other benefits is interesting. Witzke et al. [24] investigate the effects of 9 months of plyometric jump training on bone mineral content (BMC) in adolescent girls and found plyometric jump training continued over a longer period of time during adolescent growth may increase peak bone mass. Use of plyometric training in professional and recreational athletes is widespread and improvements in physical fitness and skills performance have been reported. Ramírez-Campillo et al. [101] concluded that short-term plyometric training could be advantageous for middle and long distance runners in their competitive performance, especially in events characterized by sprinting actions with small time differences at the end of the race.

There are debates among coaches and trainers designing volume and duration of plyometric trainings. Luebbers et al. [95] examined the effects of 2 plyometric training programs, equalized for training volume, followed by a 4-week recovery period of non-plyometric training on anaerobic power and vertical jump performance in physically active men and showed that four-week and 7-week plyometric programs are equally effective for improving vertical jump height, vertical jump power, and anaerobic power when followed by a 4-week recovery period. However, a 4-week program may not be as effective as a 7-week program if the recovery period is not employed. Khlifa et al. examined examine the effect of a standard plyometric training protocol with or without added load in improving vertical jumping ability in male basketball players and found that loads added to standard plyometric training program may result in greater vertical and horizontal-jump performances in basketball players [100]. Váczi et al. investigated the effects of a short-term in-season plyometric training program on power, agility and knee extensor strength of male soccer and concluded that short-term plyometric training should be incorporated in the in-season preparation of lower level players to improve specific performance in soccer [102]. Sedano et al. examined how explosive strength, kicking speed, and body composition are affected by a 12-week plyometric training program in elite female soccer players and found that 12-week plyometric program can improve explosive strength in female soccer players and that these improvements can be transferred to soccer kick performance in terms of ball speed. However, players need time to transfer these improvements in strength to the specific task. Regular soccer training can maintain the improvements from a plyometric training program for several weeks [103].

Biomechanical assessment in plyometric training is a great challenging for investigators. Ebben et al. assessed the kinetic characteristics of a variety of plyometric exercises as well as gender differences that can be used to guide the progression of plyometric training by incorporating exercises of increasing intensity over the course of a program. In these variables such as takeoff, airborne, and landing phase of each plyometric including the peak vertical ground reaction force (GRF) during takeoff, the time to takeoff, flight time, JH, peak power, landing rate of force development, and peak vertical GRF during landing [104]. Although many studies proved performance enhancements following a plyometric training program few studies disagreed. Ebben et al. investigate the motor unit activation of the quadriceps (Q), hamstring (H), and gastrocnemius (G) muscle groups during a variety of plyometric exercises to further understand the nature of these exercises. No significant main effects were found for the hamstring muscle group [105]. As Kannas et al. investigated the effects of incline plyometrics training on muscle activation and architecture during vertical jumping and maximum strength no significant changes in Isokinetic and isometric strength of the plantar flexors after training was reported [106]. Pairwise comparisons revealed a variety of differences among plyometric exercises. In some cases, plyometrics previously reported to be of high intensity, such as the depth jump, yielded relatively little motor unit recruitment compared with exercises typically thought to be of low intensity [105]. Plyometric training is a popular method by which athletes may increase power and explosiveness, but this type of training is considered a highly intense and potentially damaging activity particularly if practiced by the novice individual or if overdone. Some researchers tried to compare vertical jump performance after land- and aquatic-based plyometric training. Martel et al. studied muscular strength, joint stability, and vertical jump (VJ) in volleyball players following an aquatic plyometric training (APT) program and concluded that a combination of APT and volleyball training may cause in larger improvements in VJ. Given the likely reduction in muscle soreness with APT versus land-based plyometrics, APT appears to be a promising training option [52]. In a similar study Stemm et al. suggested that no significant difference was found in vertical jump performance between the aquatic- and land-based groups. It was concluded that aquatic training resulted in similar training effects as land-based training, with a possible reduction in stress due to the reduction of impact afforded by the buoyancy and resistance of the water upon landing [107]. Donoghue et al. quantified the landing kinetics during a range of typical lower limb plyometric exercises performed on land and in water and results showed that significant reductions were observed in peak impact forces (33%-54%), impulse (19%-54%), and rate of force development (33%-62%) in water compared with land for the majority of exercises [108].

3.4 Combined Training

Multiple training regimens seem to represent an effective training stimulus because the combination of single training stimuli produces major neuromuscular adaptations. This can for instance affect different parts of the force–velocity-relation [109]. Combination of resistance and plyometric training is important, especially for professional athletes. Common form is executing similar high load and plyometric movements in three sets such as squat and squat jump. Benefits of this kind of training have interested many researchers [110,111,112,113,114,115]. Earlier, Ebben & Watts reported positive effects of combining resistance and plyometric training and need for more investigations was suggested [116]. Other researchers evaluated effectiveness of combined training such as dynamic warm up and resistance training on vertical jump [117,118,119,120,121,122,123]. Improvements of motor performance were reported by some researchers through combining resistance and plyometrics training comparing other modalities [124,125,126,127,128,129,130,131]. In some cases, effect of combined resistance and plyometrics training was investigated on functional parameters with respect to upper and lower extremities. Ebben et al. [118] did not report any significant differences in vertical ground reaction force and electrical activity of muscles following a combined training, including bench press and medicine ball throwing. Similar results were observed in females [121]. Conversely, Evans et al. (2000) showed a significant increase in throwing distance of medicine ball after combining with bench press [119]. Radcliffe & Radcliffe reported increase in long jump following dynamic warm up using resistance training such as snatch, squat, loaded jumping and tuck jump, but not significantly [122]. Young et al. [132] suggested that performing high intensity squat training four minutes before jumping could result in performance improvement. Zepeda & Gonzalez showed significant improvement in functional factors such as agility, speed and VO_2 in female basketball players following a combined resistance and plyometrics training programs [123]. Designing combined programs should be upon important variables like training modalities, load and rest intervals. New researches have challenged age and gender. Combined training had more significant effects on male comparing females [122]. Strength is the prerequisite of designing combined training [132]. Kubo et al. [133] studied the effects of plyometric and weight training protocols on the mechanical properties of muscle-tendon complex and muscle activities and performances during jumping. The relative increases in jump heights were significantly greater for plyometric training than for weight training and no significant differences in the changes in the Electromyographic activities of measured muscles during jumping was observed between groups. These results indicate that the jump performance gains after plyometric training are attributed to changes in the mechanical properties of muscle-tendon complex, rather than to the muscle activation strategies. Combination of resistance and plyometrics training are of the great interests in early childhood and adolescents, especially for those who are engaged in professional sports. Results of Faigenbaum et al. showed similar increases in boys and girls following resistance and plyometrics training in early childhood [25]. Keiner et al. evaluate how 2 years of additional strength training and plyometric training in elite 9 to 12 years old soccer player affects their performance in the squat jump (SJ), countermovement jump (CMJ) and drop jump (DJ). Results also showed in most variables significant better performances [83]. Few researchers have focused on the effects of combining resistance training and plyometric training together on various parameters of skills and movements in children and adolescents [15,18,129]. According to the study of Faigenbaum et al. the effects six weeks of resistance training and plyometric training may be synergistic in children and adolescents, with their combined effects being greater that each program performed alone [19]. Among sport conditioning coaches, there is considerable discussion regarding the efficiency of training methods that improve lower-body power. Santos et al. evaluate the effects of a complex training program, a combined practice of weight training and plyometrics, on explosive strength development of twenty five young male basketball players. Results support the use of complex training to improve the explosiveness level of upper and lower body in young basketball players [18]. Grieco et al. investigated the effect of a 10-week combined resistance-plyometric training program on the Running Economy (RE) and $V_{\mathbf{O2max}}$ in female soccer players and showed that a plyometric-agility training program may increase the $V_{\mathbf{O2peak}}$ in female soccer players but the effect on RE still remains unknown [134]. Mihalik et al. determined performing a minimum of 3 weeks of either complex training is effective for improving vertical jump height and power output in volleyball players and coaches should choose the program which best suits their training schedules [135]. De Villarrea et al. examined the effects of 5 different stimuli on jumping ability and power production after 7 weeks of training on 5 experimental groups. The results of this study provide evidence to suggest that if training program is designed and implemented correctly, both traditional slow velocity training and faster power-oriented strength training alone, or in combination with plyometric training, would provide a positive training stimulus to enhance jumping performance [136]. Marina et al. studied the effectiveness of a combined strength and plyometric training program on jumping performance when compared to a training routine on apparatus over two successive gymnastics training season and concluded that a combination of heavy resistance training with high impact plyometric jumps is effective in pre-pubertal gymnasts, in spite of their initial high level of physical conditioning [137]. Study of the effect of an 8-week training program with heavy- vs. light-load jump squats on various physical performance measures and electromyography (EMG) indicates increased movement velocity capabilities and velocity-specific change in muscle activity in this adaptation [138]. Arabatz et al. compared the effect of various training program for improving vertical jump, including weight lifting (W), a plyometric (PL), and combined weight lifting + plyometric (WP) training program and reported improvement in all groups [139]. In a similar study Tricol et al. reported significant improvement on athletes’ performance after heavy resistance training combined with either the vertical jump (VJ) training or weight lifting (WL) program [140]. However not all studies show augmentations of RT and plyometric training. Wilson et al. showed that eight weeks of RT consisting of 6 sets of 6-10 repetitions of squat produce the similar increase in vertical jump height to plyometric training consisting of 3-6 sets of 8 repetitions of depth jumps [141]. Carlson et al. compared the effects of different types of RT and combined training including resistance training and plyometric on vertical jump. Findings of this study demonstrate that there is no difference in vertical jump among different training group over a 6-week timeframe [142]. Ronnestad et al. observed positive effects of combined training on functional variables such as jumping in soccer players, but already not significant compared to resistance training alone [143]. These disagreements could be interpreted by short period of training or inappropriate training programs. Wilson et al. investigated the adaptations invoked by plyometric and weight training. Results were attributed to the specific stresses imposed by the differing forms of training and are discussed with reference to methods of enhancing training induced adaptations and the types of movements such training would tend to facilitate [141]. Many researchers have tried to find new methods of training by combining new methods of training plus plyometric and assessing the results. Herrero et al. showed that Electromyostimulation (EMS) and plyometric training (P), or combined EMS and P training of the knee extensor increased jumping height and sprint run in physically active men. In addition, EMS alone or EMS combined with plyometric training leads to increase maximal strength and to some hypertrophy of trained muscles. However, EMS training alone did not result in any improvement in jumping explosive strength development or even interfered in sprint run [144]. Voelzke et al. compared the impact of short term training with resistance plus plyometric training (RT+P) or Electromyostimulation plus plyometric training (EMS+P) on explosive force production in elite volleyball players and concluded that RT+P training is effective in promoting jump performances and EMS+P training increases jump, speed and agility performances of elite volleyball players significantly [49]. Martinez Lopez et al. examined the effects of eight-week (2 days/week) training periods of plyometric exercises (PT) and neuromuscular Electro stimulation (EMS) on jump height in young athletes. Findings suggest that compared to control (Plyometrics (PT) only), the combination of 150Hz EMS + PT simultaneously combined with an 8 week (2days/week) training program result significant jump height improvements in the different types of strength: explosive, explosive-elastic, and explosive-elastic-reactive. The combination of PT after ≤ 85 Hz EMS did not show any jump height significant increase in sprinters. An eight week training program (with just two days per week) of EMS combined with plyometric exercises has proven useful for the improvement of every kind of vertical jump ability required for sprint and hurdle disciplines in teenage athletes [15].

Review of the studies shows that many of them focused on effects of combined training (PT+RT) on muscular power and physical fitness parameters of athletes. Little is known about combined training on children and adolescents especially when engaged with a regular sport and physical activity. A great challenge still remains that what is the most appropriate training program for children and adolescents and how to interpret results of performing a skill in children from biomechanical viewpoint.

3.5 Guidelines and Recommendation

Guidelines and recommendations state that RT and PT can be a safe and worthwhile activity if appropriately designed and competently supervised. Coaches, teachers, and trainers must have a thorough understanding of guidelines and safety procedures. All exercises must be clearly explained and properly demonstrated to all participants, Factors such as cost, quality of instruction, adjustability, proper fit, and weight stack increments should be considered when evaluating training equipment for children and adolescents. For example, child-sized weight machines are a viable alternative and have proven to be safe and effective for children and adolescents. Single-joint (e.g., leg extension) and multi-joint (e.g., squat) exercises can be incorporated into youth strength-training programs. Single-joint exercises are relatively easy to perform and are appropriate when activation of a specific muscle group is desired, whereas multi-joint exercises require the coordinated action of many muscle groups. Another issue concerning the choice of exercise is the inclusion of functional exercises for the “core” of the trainer’s body (i.e., the hips, abdomen, and lower back). It seems young athletes sometimes spend too much time training their extremities (e.g., arms) and not enough time (or no time at all) strengthening their core musculature. Depending on the needs of the young athlete and the demands of the sport, other prehabilitation exercises (e.g., internal and external rotation) can be incorporated into the workout. Guidelines for incorporating medicine ball training into a youth strength training workout are available elsewhere.

4. SUMMARY

Numerous beneficial effects have been reported on muscular strength, prevention and rehabilitation of injuries, long term health, cardiovascular fitness, body composition, bone mineral density, blood lipid profiles and self-esteem, depression and mental health in children and adolescents while using RT [22,38,46,58,62,64,65,76,80,81,82,83]. Plyometric training has increased athletic performance in most studies. Plyometric trainings are useful for children and adolescents to improve their physical abilities if appropriate program and necessary precautions are considered [20,23,24,90,96,98]. Plyometric training can increase jumping height and power [95,99,124,125,145], sprinting ability [99,145] and agility [145]. Plyometric training increases muscle strength and hypertrophy as well as induces fiber type transitions similar to RT [13,125]. Combination of RT and plyometric is a useful method for improving performance especially jumping ability but less in known about the effects in children and adolescents [18,19,83,109,135,136]. There would be great interest about the effects of various methods of training on children and adolescents especially to improve skills performance with respect to biomechanical viewpoints.

As a power sport including forceful and high repeated jumping and landing, mini volleyball players according to their little experience and age are easily subject to injury. Clearly, more research is needed to understand young children’s response to different types of exercises, which are designed for enhancement and improvement of performance. It will also be necessary to determine the safest and most effective method for progressing exercise load and to clarify the need for strength or motor skill prerequisites for participating in these training.

5. CONCLUSION

Importance of physical activity and participating in organized sports for children and adolescents is evident and clear for everyone. It is recommended that children and adolescents to be engaged in different training modalities such as resistance, plyometric and even combined training in order to achieve good physical fitness as well as optimized performance. Safety regulations and precautions should be considered during these training programs. Participating in combined resistance and plyometric training would be more efficient especially for children and adolescents to perform jumping tasks in volleyball. More research is needed to evaluate effect size of different training modalities as well as other effective training programs for other physical fitness parameters in other sports.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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