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STRENGTH DIFFERENCES BETWEEN TRAINED AND UNTRAINED PRE-PUBERTAL CHILDREN: STRETCH-SHORTENING CYCLE OF MUSCLE CONTRACTIONS

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ABSTRACT

This study investigated jumping performance in pre-pubertal children with respect to age, gender and trained level and their ability to use the stretch-shortening cycle (SSC). One hundred and twenty-seven (n=127) children participated in this study that included 66 from a basketball academy (age: 9.88±1.38 years) and 61 sedentary schoolchildren (age: 9.93±1.55 years). Neuromuscular variables, such as the Squat Jump (SJ), the Counter Movement Jump (CMJ), the Drop Jump (DJ) and the Standing Long Jump (SLJ) were measured. There were no significant differences between boys and girls in all the jumps for the basketball group. In the sedentary group, boys exhibit higher scores in DJ-40cm than the girls. The trained group achieves better scores in several jumps than the sedentary group. Significant differences between the sedentary and trained groups in relation to different age groups are found in all the jumps. High scores on the DJ-40cm and SLJ are a risk factor for trained status. Pre-pubertal children exhibit considerable trainability in relation to explosive leg strength; however, there is an inability to use the stretch-shortening cycle to vertical jumping performance.

***Keywords*:** Strength; Children; Trainability; Jump performance.

INTRODUCTION

Basketball is a team game that combines cyclic and acyclic movements that are performed either with the ball or without the ball (Erčulj *et al*., 2010). As in most team sports, basketball exhibits several explosive ballistic actions, such as running sprint, jumps, accelerations/decelerations, and changes of direction (Gottlieb *et al*., 2014). Moreover, this team game demands various technical and tactical skills. Basketball players travel 5–6km at physiological intensities above lactate threshold and 85% of maximal heart rate (Stojanović *et al*., 2018). The most common injury site is the knee, followed by the foot and ankle, the anterior cruciate ligament injury and the ankle sprain, are the main injuries(Iwamoto *et al*., 2014).

Human movement, such as jumping, hopping, leaping, sprinting, skipping and other bounding movements are improved by making a counter-movement as these activities utilise the stretch-shortening cycle (SSC) movements. SSC is considered a naturally occurring muscle action for most forms of human locomotion (Radnor *et al*., 2018), which means a combination of eccentric and concentric contractions are involved with a muscle function (Komi, 2000).

Some fitness tests to evaluate jumping are the squat jump (SJ), the counter movement jump (CMJ) and the drop jump (DJ). Plyometric exercises, such as CMJ and DJ involves SSC in which a muscle is stretched before its explosive contraction (Lazaridis *et al*., 2010).

Skeletal muscle possesses an intrinsic ability to adapt to the type of physical activity performed. The adaptation takes place during normal growth and as a response to exercise training (Komi, 2008). Two training methods, resistance and plyometric training (PT), are usually employed for improving the explosive strength in basketball players (Santos & Janeira, 2008). Plyometric training (jumping, bounding and hopping exercises that use the stretch-shortening cycle of the muscle unit) improves the production of muscle force and power (Häkkinen, 1985; Wagner & Kocak, 1997). The time available for force development, the potentiation of the muscle contraction, the effects of stretch-reflexes and the storage and re-utilisation of elastic energy have been raised as reasons to improve the vertical jump using countermovement (Gerodimos *et al.*, 2008).

Several authors showed that during the growth years, the skeletal musculature exhibits structural, neural and metabolic changes. These include excitability, neuromuscular activation, contractile properties, leg stiffness, the capacity to store and use elastic energy and stretch reflex potentiation, concentric strength, movement coordination and motor control, lesser capacity to generate mechanical energy from chemical energy sources during short-term intensive activity(Van Praagh & Doré, 2002; Gerodimos *et al*., 2008; Lloyd *et al*., 2010; Lloyd *et al*., 2011a). These could affect jumping performance in children. Studies have shown the existence of critical or sensitive periods in motor learning and the improvement of motor abilities. In the age range from 5–18 years, the first period is from 5–9 years (pre-pubertal stage), which is characterised by increased muscle strength, explosive power, speed and aerobic endurance. In the second period, which occurs in the post-pubertal stage, is associated with gender maturation and an accelerated improvement in strength, explosive strength and aerobic endurance (Viru *et al*., 1999).

Although it is suggested that periods of naturally occurring accelerated adaptation may exist for various physical parameters, it would appear that no such evidence exists for SSC development (Lloyd *al.*, 2011a). SSC improves with age in a nonlinear way, with the possible existence of periods of accelerated adaptation (Lloyd *et al*., 2011b). In particular, Lazaridis *et al*. (2013) show that during growth, boys continuously increase their performance in jump height, whereas girls reach a plateau after puberty. It seems possible that these results are due to puberty when the girls experience less dramatic gains in skeletal tissue and muscle mass (Quatman *et al*., 2006). Moreover, the fattest girls generally show poorer motor fitness than boys (Malina *et al*., 1995).

Therefore, the exercises that include SSC have not been sufficiently studied during the growth period (Bassa *et al*., 2012) and studies are controversial. Pääsuke *et al*. (2001) indicated an inability to use the positive effect of SSC on vertical jumping performance in pre-and post-pubertal boys. However, Gerodimos *et al*. (2008) showed that the ability to use the SSC to augment vertical jump (SJ, CMJ) is not affected by the maturation process in male basketball players throughout the growth period (12–17-year-olds) and is similar to that in young adults. Recent studies show that pre-pubertal children exhibit high trainability of SSC (Latorre-Román *et al*., 2018).

Therefore, jumping performance is regarded as the main fitness determinant of team sport players (such as volleyball, basketball, handball) and needs to be considered from an early stage of the development of players. Along the maturation process, SSC development throughout childhood allows children to increase power to run faster and jump higher. However, the mechanisms of SSC development during maturational years are not very clear (Radnor *et al*., 2018).

PURPOSE OF THE STUDY

For the reasons mentioned above, the purpose of this study was to investigate jumping performance in pre-pubertal children with respect to age, gender and trained level, and the ability to use the stretch-shortening cycle.

METHODOLOGY

Participants

One hundred and twenty-seven (n=127) children participated in this study, of which 66 were from a basketball academy (age: 9.88±1.38 years; BMI: 18.87±3.74 kg/m^2) and 61 were sedentary schoolchildren (age: 9.93±1.55 years; BMI: 18.08±5.49 kg/m^2). The participants were divided according to their chronological age into three groups: 7-8 years, 9-10 years and 11-12 years. Pubertal stages were determined according to Tanner (1957). All the children were in Tanner Stage 1 (pre-pubertal age).

All children, parents and coaches were informed of the protocol, the experimental risks, and parents signed an informed consent document before the investigation. The study was conducted in the basketball season, where players attended training three times per week and played competitive matches at least once a week; and had no history of injury in the three months prior to the study, which would limit training. Moreover, all players had been involved in basketball training of this regularity for at least two years before the study. They were exposed to the same basketball-training stimulus with regard to volume and intensity. Data collection took place in the middle of the season.

Ethical clearance

The study was conducted, in adherence to the standards of the Declaration of Helsinki (2013 version). The investigation and the informed consent form were approved for use by the Ethics Committee from the University of Jaen, Spain.

Measures and procedures

Height (cm) was measured with a stadiometer (Seca 222, Hamburg, Germany) and weight with a weighing scale (Seca 899, Hamburg, Germany). Body mass index (BMI) was calculated by dividing weight (in kilograms) by height^2 (in metres). Neuromuscular variables consisting of SJ, CMJ and DJ were recorded using the OptoGait system (Microgate, Bolzano, Italy). This device measures the contact time on the floor and the flight time using photoelectric cells. Flight time was used to calculate the height of the rise using the body's centre of gravity. The contribution of SSC was calculated by the difference of CMJ and SJ in centimetre (Young, 1995). The standing long jump (SLJ) was used (España-Romero *et al*., 2010) also.

Experimental procedure

The participants were tested on one specific day. They were asked not to engage in any heavy-intensity exercise for 72 hours before the experiment. Testing sessions began with a warm-up, consisting of 5 minutes of low-intensity running, and 5 minutes of general exercises (high skipping, leg flexions, lateral running, front and behind arm rotation, and sprints). At the beginning of the testing day, a familiarisation with the jumping tests used and anthropometric and fitness test assessment, SJ, CMJ and DJ according to the protocol described by Bosco (Bosco, 1987) and SLJ were carried out. During the SJ, CMJ and DJ, the participant maintained their trunk upright and their hands on hips to eliminate the influence of arm swing. In DJ, the subject stood on a box, 20cm and 40cm high. Each jump was repeated three times, the heights of all jumps were recorded and the best performance was registered in centimetres (cm) for analysis. The participants were instructed to maximise jump height.

Statistical analysis

Data were analysed using SPSS, v.19.0 for Windows (SPSS Inc, Chicago, USA) and the significance level was set at $p<0.05$. The data are shown in descriptive statistics of the mean and standard deviation (SD). Tests of normal distribution and homogeneity (Kolmogorov-Smirnov and Levene's respectively) were conducted on all data before analysis. Differences between groups were analysed using analysis of variance (ANOVA) adjusting with Bonferroni test post hoc comparisons for differences between gender and age groups and for each jumping variable. In addition, effect sizes for group differences were calculated through Partial Eta^2. Effect sizes were analysed as trivial (<0.2), small (0.2–0.49), medium (0.5–0.79), and large (>0.8) (Cohen, 1988).

The jumping threshold that best discriminates between the sedentary and athletic condition was determined by using the receiver operating characteristic (ROC) curve. Binary logistic regression was performed using as dependent variable the sedentary and athletic condition and as independent variable the jumping test. The reliability of Bosco protocol and SLJ through the intraclass correlation coefficient (ICC) and heteroscedasticity was analysed by pre-test-retest. A week after the pre-test, 35 children (included in the previous data collection) selected randomly, performed the same test (re-test). For the analysis of heteroscedasticity, mean differences in relation to the individual values were computed. The correlation coefficient was calculated to examine the presence of heteroscedasticity (Atkinson & Nevill, 1998).

RESULTS

Table 1 shows the results of the analysis of reliability by means of the Bosco protocol and SLJ using test-retest. Table 2 provides the age and anthropometric characteristics of the young basketball players and sedentary children who participated. The trained group showed greater height than the sedentary group.

Table 3 shows the results of the different jumps in both groups in relation to gender. There are no significant differences for both boys and girls in the basketball group in all jumps. In the sedentary group, boys achieve a better score in DJ-40 than girls. The comparison between groups indicates that the trained group achieves better scores in several jumps than the sedentary group, girls in all jumps and boys only in DJ-20, DJ-40 and SLJ. Moreover, there are no significant differences in SSC. There are no significant differences between all vertical jump heights for both genders and girls in the basketball players and sedentary groups. However, in the total group the CMJ is the better jump with significant differences in relation to the DJ-20 and DJ-40, for both boys and girls.

***Table 1*. RELIABILITY OF BOSCO PROTOCOL AND SLJ USING TEST-RETEST**

Variables	**Pre-test** n=35 **Mean±SD**	**Post-test** n=35 **Mean±SD**	**p-value**	**ICC**	**p-value**	**95% Confidence Interval**	**Hetero sceda-sticity**	**p-Value**
SJ (cm)	17.10±4.07	17.21±4.19	0.713	0.951	<0.001	0.902-0.975	0.135	0.439
CMJ (cm)	17.47±3.93	17.93±3.80	0.112	0.950	<0.001	0.902-0.975	0.197	0.257
DJ 20 (cm)	15.16±5.20	15.55±4.28	0.279	0.940	<0.001	0.882-0.970	-0.121	0.488
DJ 40 (cm)	15.22±4.97	15.32±4.12	0.793	0.986	<0.001	0.971-0.993	-0.191	0.271
SLJ (cm)	121.83±21.49	123.57±22.57	0.058	0.959	<0.001	0.919-0.979	-104.000	0.553

SD=Standard Deviation; ICC=Intraclass Correlation Coefficient; SJ=Squat Jump; CMJ=Counter Movement Jump; DJ=Drop Jump; SLJ=Standing Long Jump

***Table 2*. PHYSICAL CHARACTERISTICS OF PARTICIPANTS**

Variables	**Sedentary group** n=61 **Mean±SD**	**Basketball players** n=66 **Mean (SD)**	**p-Value**
Age (years)	9.93±1.55	9.88±1.38	0.832
Body Mass (kg)	39.85±11.80	43.04±14.19	0.178
Body Height (m)	1.43±0.10	1.49±0.14	0.012
BMI (kg/m^2)	18.08±5.49	18.87±3.74	0.343
Boys/Girls [n (%)]	32 (42.1)/29 (56.9)	44 (57.9)/22(43.1)	0.103

SD=Standard Deviation; BMI=Body Mass Index

***Table 3*.** **JUMP PERFORMANCE IN SEDENTARY AND TRAINED GROUP IN RELATION TO GENDER**

	Whole group				**Sedentary group**				**Basketball players group**			
Jumps	**Boys** n=76 M±SD	**Girls** n=51 M±SD	p-Value	η^2	**Boys** n=32 M±SD	**Girls** n=29 M±SD	p-Value	η^2	**Boys** n=44 M±SD	**Girls** n=22 M±SD	p-Value	η^2
SJ cm	19.56±5.61	17.66±5.44	0.137	0.018	18.33±4.35	16.05±4.63	0.102	0.022	20.45±6.26	19.78±5.79*	0.634	0.002
CMJ cm	20.26±5.54ǂǂ	18.35±5.12ǂ	0.122	0.019	18.92±3.72	16.84±4.58	0.123	0.019	21.23±6.43	20.33±5.22*	0.510	0.004
SSC cm	0.704±2.26	0.690±2.39	0.974	0.001	0.594±2.67	0.793±2.18	0.740	0.001	0.784±1.95	0.555±2.69	0.707	0.001
DJ-20 cm	18.57±5.68	16.77±4.93	0.190	0.014	16.53±4.52	14.95±3.68	0.228	0.012	20.05±6.03*	19.17±5.40*	0.513	0.003
DJ-40 cm	18.43±5.80	15.82±5.57	0.050	0.031	16.42±5.09	13.04±3.67	0.013	0.049	19.90±5.89*	19.50±5.58*	0.768	0.001
SLJ cm	140.83±27.24	127.08±25.01	0.019	0.044	128.53±21.99	117.83±21.94	0.089	0.023	149.77±27.42*	139.27±23.95*	0.101	0.022

*Significant differences with sedentary group ($p<0.05$); ǂ Significant differences with DJ-20 and DJ-40 ($p<0.05$). ǂǂ Significant differences with DJ-20 and DJ-40 ($p<0.01$) in whole group

M=Mean; SD=Standard Deviation; SJ=Squat Jump; CMJ=Counter Movement Jump; SSC=Stretch-shortening cycle; DJ=Drop Jump; SLJ=Standing Long Jump.

Table 4. JUMP PERFORMANCE IN SEDENTARY AND TRAINED GROUP IN RELATION TO AGE

	Sedentary Group					**Trained Group**					
Jumps	**7-8 years** n=16 M±SD	**9-10 years** n=20 M±SD	**11-12 years** n=25 M±SD	p-Value	η^2	**7-8 years[a]** n=13 M±SD	**9-10 years[b]** n=27 M±SD	**11-12 years[c]** n=26 M±SD	p-Value	η^2	**Post-hoc**
SJ cm	17.05±3.29	15.88±3.66	18.46±5.68	0.264	0.022	17.80±4.77	19.20±5.54*	22.51±6.59**	0.015	0.067	a<c ǂ
CMJ cm	17.11±3.56	17.17± (3.27	19.07±5.14	0.349	0.017	18.56±4.44	19.71±5.68	23.38±6.38**	0.007	0.079	a<c ǂ, b<cǂ
SSC cm	0.063±2.79	1.285±1.98	0.612±2.50	0.292	0.020	0.769±1.44	0.519±1.88	0.873±2.81	0.853	0.003	–
DJ-20 cm	14.86±2.86	15.59±3.41	16.53±5.32	0.547	0.010	17.31±4.80	18.05±5.25	22.74±5.67***	0.001	0.121	a<c ǂǂ, b<cǂǂ
DJ-40 cm	13.55±3.40	13.69±3.90	16.52±5.66	0.088	0.039	17.33±4.54*	18.11±5.49**	22.70±5.45***	0.001	0.110	a<c ǂǂ, b<cǂǂ
SLJ cm	119.62±20.72	116.30±15.58	131.60±26.01	0.084	0.040	142.00±19.81*	139.63±29.73**	155.31±24.29**	0.050	0.048	–

Significant idfferences with sedentary group: * p<0.05 **p<0.01 ***p<0.001 ǂ p<0.05 ǂǂ p<0.001
M=Mean; SD=Standard deviation; SJ=Squat Jump; CMJ=Counter Movement Jump; SSC=Stretch Shortening Cycle; DJ=Drop Jump; SLJ=Standing Long Jump

Jumping performance in the sedentary and trained group in relation to age groups was shown in Table 4. In the sedentary group, there are no significant differences in all the jumps and SSC in relation to age groups, however, in the trained group, during the growth period there is a better vertical jump performance. Furthermore, significant differences between the sedentary and trained groups in relation to different age groups are found.

The binary logistic regression analysis using as the dependent variable sedentary-trained condition reveals that a high score on the DJ-40 (Odds Ratio=1.194; I.C. 95%=1.015-1.405; p=0.033) and SLJ (Odds Ratio=1.029; I.C. 95%=1.003-1.055; p=0.026) are a risk factor for trained status.

Figure 1 shows the ROC curve of the sedentary-trained condition predicted by the DJ-40 (area under the curve [AUC]=0.742; IC 95%=0.657-0.827; p=<0.001), and SLJ (AUC=0.754; IC 95%=0.669-0.840; p=<0.001) reaching the cutting point in 17cm (sensitivity=0.636; 1-especificity=0.279) for DJ-40 and 140cm (sensitivity=0.606; 1-especificity=0.197) for SLJ.

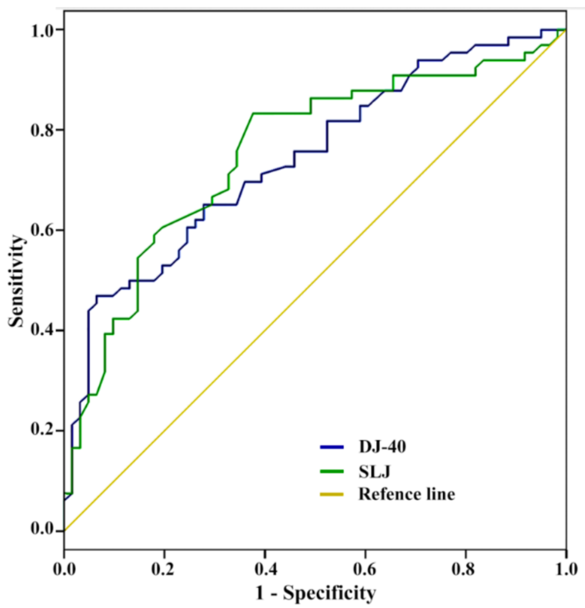

Figure 1. **ROC CURVE INDICATING POTENTIAL OF DJ-40 AND SLJ TO IDENTIFY SEDENTARY AND TRAINED CONDITION**

DISCUSSION

The purpose of this study was to investigate jumping performance in pre-pubertal children with respect to age, gender and trained level. Adequate reliability parameters were found in the Bosco protocol and SLJ for children aged 7 to 12 years. The main finding of this study was that the pre-pubertal trained group achieved better scores than the sedentary group in different jumps. The findings of this study suggest that the trained young athletes have better coordination and strength than their untrained counterparts (Iadreev *et al*., 2015). Likewise, Bassa *et al*. (2012) indicated that pre-pubertal trained boys and girls had statistically significantly greater vertical jump height (SJ, CMJ and DJ) values than untrained ones. Among all the jump tests, the DJ-40 and SLJ show a significant capacity to discriminate between trained and sedentary pre-pubertal children.

In relation to gender, no significant differences were found in jumping performance in the trained group. However, in the whole group, there is a significant difference in SLJ in relation to gender. This result is in accordance with the study of Marta *et al*. (2012), which showed physical fitness differences between pre-pubescent boys and girls, especially in SLJ. Furthermore, in this study, it was found that boys showed a higher score in DJ-40 than girls in the sedentary group. There are no significant differences between all vertical jump heights for both the children and girls basketball players and sedentary groups. However, in the total group CMJ is the better jump with significant differences in relation to the DJ-20 and DJ-40, for both boys and girls.

Non-improvements of performance in DJ in relation to SJ and CMJ indicate that both trained and sedentary children could not use the SSC effectively. These results are in agreement with those of Bassa *et al*. (2012), which demonstrated that for pre-pubertal children, the jump height in CMJ was significantly higher in relation to SJ and DJ (10-20-30-40-50cm.). In particular, in relation to SSC, there are no significant differences between the sedentary group and trained group for both boys and girls or between age groups. These results could be explained by the inability to use the SSC for vertical jumping performance in pre- and post-pubertal boys (Paasuke *et al.*, 2001). The lack of pre-stretch, lower stiffness and incomplete extension in the pre-pubertal children (6 years old) is thought to influence jumping performance (Wang *et al.*, 2004). Moreover, poorer performance in SJ, CMJ and DJ between 20cm and 40cm in boys in relation to adults could be partially due to their poorer technique revealed by their lower agonist and higher antagonist activation (Lazaridis *et al.*, 2013).

In the same context, Lazaridis *et al*. (2010) conducted a comparison between men and pre-pubescent boys in DJ from a 20-cm height; the higher jump height of the men could be due to a better muscle activation before landing and during the braking phase. Besides, the pre-pubescent boys showed a poorer regulation of their muscle–tendon unit. In this study, no improvements in DJ-20 and DJ-40 were found in both the sedentary group and trained group. Therefore, training by DJ in children is questionable, especially when using drop heights of between 20cm and 40cm, since these drop jumps resulted in no benefit to their performance (Lazaridis *et al*., 2013).

In relation to age and jumping performance (SJ, CMJ) improvement along with growth, there are gender differences from 14 years onwards due to the higher increase in leg length and muscle volume in boys than in girls (Temfemo *et al*., 2009). Likewise, Gerodimos *et al*. (2008) showed that SJ and CMJ performances increased with age from pre-pubertal children to adolescents. Especially, between 10.0–15.9 years old, jump height increased significantly year after year for boys, however, jump height reached a plateau after age 12 for the girls (Taylor *et al*., 2010). In this study, only in the trained group, jumping performance is higher in relation to age. On the other hand, SSC improves with age in various forms of jumping, and sprinting tasks, with the possible existence of periods of accelerated adaptation.

It seems possible that these findings are due to a higher level of coordination, because during growth and maturation there are several changes in the neuromuscular system, such as pre-activation, fascicle length, tendon stiffness, reactive strength index and elastic energy re-utilisation (Lloyd *et al*., 2011b; Radnor *et al*., 2018). Nevertheless, in this study, SSC did not show changes with age in pre-pubertal population. These findings further support the idea that the pre-pubertal stage is more efficient at storing energy in slow SSC movements, such as a CMJ than in fast SSC movements (Moran *et al*., 2017), such as maximal DJ.

Motor skill performance and physical fitness have been shown to be positively associated with physical activity in cross-sectional studies (Fisher *et al*., 2005; Williams *et al*., 2008; Aires *et al*., 2010) and longitudinal studies (Lopes *et al*., 2011; Larsen *et al*., 2014). Specifically, vertical jump, was significantly associated with time spent in moderate to vigorous physical activity at three-year follow-up in children (Larsen *et al*., 2014). This study found that DJ-40 and SLJ are predictive variables for sedentary and trained condition in pre-pubertal children.

LIMITATIONS

The main limitation in this study is its cross-sectional design (level of muscular strength in growing children must be measured in longitudinal research). However, the strengths of this study include a population sample of pre-pubertal children, both sedentary and trained, and the reliability of vertical jump and SLJ in this population.

CONCLUSION

From a practical point of view, the absence of better performance in DJ compared to SJ and CMJ in both trained and untrained children indicates that there is no optimal drop height are consistent with the results reported by Bassa *et al*. (2012). This could be an indication that the training of jump capacity in children should take into account eccentric loading for optimal utilisation of SSC, which must be clarified. Future research should test the efficacy of PT in pre-pubertal children. In conclusion, the trained group achieved better scores than the sedentary group in different jumps. However, it is not possible to use the SSC for vertical jumping performance in pre-pubertal children. Finally, DJ-40 and SLJ show a significant capacity to discriminate between trained and sedentary pre-pubertal children.

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