Chapter 3

Effects of Football Training on School Children Evaluated Through Quantitative Muscle Ultrasound

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Abstract

The aim of this study was to evaluate the effect of specific training on vertical jump and ultrasound measures of the quadriceps in school children. To this end, 37 children (8.2±0.9 years), who practised football regularly, were evaluated. The sample was divided into 3 age groups. A muscle ultrasound of the right quadriceps was performed, and the thickness and eco-intensity of the rectus femoris and vast intermediate were measured, as well as the pennation angle of the rectus femoris. Anthropometric parameters were recorded (weight, height, BMI and fat percentage). The vertical jump was measured using the CMJ test and the repeated jumps test (RJT) for 15 seconds. An initial evaluation of the participants was conducted, and a second evaluation was carried out after 10 months of training. The normality of each variable was determined and a Student's t-test or Mann-Whitney U-test was applied for paired data. The difference between the two time points was evaluated for each age group and for each variable. The obtained results indicate that the thickness of the rectus femoris and the total

Citation: *Juan Carlos Giraldo García, (2021) Sports Medicine, Vol. 1, Chapter 3, pp. 35-45.*

thickness of the quadriceps increased significantly in the three groups. The thickness of the vast intermediate increased significantly in the G7 and G8 groups. The pennation angle increased significantly in G9. The eco-intensity showed significant changes in G9. The vertical jump improved in G7. The significant changes in the quantitative ultrasound of the quadriceps indicate that the increases in muscle thickness, pennation angle and muscle quality measured by eco-intensity, along with neurological maturation, are related to the increase in vertical jump in school children who train regularly in an intermittent sport like football.

Keywords: Muscle quality, ultrasound, intermittent sports, muscle strength.

1. Introduction

Diagnostic imaging methods have been used in physical activity and sport to evaluate physiological aspects [1]. Ultrasound, which is a non-invasive technique, would be an excellent method to evaluate the muscles of children, since, for ethical reasons, invasive methods (e.g., muscle biopsy) cannot be used. Moreover, musculoskeletal ultrasound can accurately quantify muscle thickness, pen nation angle and eco-intensity, which evaluates the quality of muscle tissue from a gray-scale ultrasound image. These quantitative methods have been used mostly to evaluate muscle quality in adults [2].

Ultrasound is an excellent method for the evaluation and follow-up of muscle mass and its changes derived from training or natural development throughout life. By simultaneously conducting an ultrasound of the quadriceps (to evaluate the quantitative anatomy of the main muscle involved in the vertical jump) and the vertical jump test (to evaluate muscle strength), it would be possible to analyse the evolution of these two variables and their possible relationships. Knowing the ultrasound evolution of the muscle and the evolution of the jump as a functional development in school children would allow determining the applicability of musculoskeletal ultrasound, as well as the possibility of using it in numerous aspects of physical activity and children's sport. This leads to the following research question: How do ultrasound characteristics, especially muscle thickness, pen nation angle and eco-intensity of the quadriceps, and vertical jump change in school children who perform regular football training?.

1.1. Literature Review

In general, there are two accepted physiological adaptation mechanisms that can occur as a response to the increase of strength: Morphological and neurological. These adaptations have a different contribution in children, adolescents and adults. Hypertrophy has been demonstrated with anthropometric measures in adults, with some evidence in adolescents and none in children. The application of magnetic resonance and ultrasound to evaluate hypertrophy has shown muscle size increases in prepubertal children [2]. Ultrasound is an excellent tool to evaluate skeletal muscle quantitatively, e.g., by analysing muscle thickness, which is strongly correlated with the area of the cross section of the muscle [3,4], the pennation angle and eco-intensity.

Most of the activities of daily living of children and adolescents are characterised by their short duration and high intensity; that is, they depend on mechanisms of anaerobic production [5,6]. During a football match, the players constantly use abilities such as short supra-maximal sprints and jumps, which employ anaerobic power. Therefore, those who train in this sport could show better performance in anaerobic tests. In a study conducted by Bencke (2002) in prepubertal and pubescent children who practised several sports, the results indicated that the specific training exerted some influence, especially on the complex motor responses, such as the jump, suggesting that this could be an indicator of the effect of training before puberty. Thus, the aim of the present study was to evaluate the effects of regular football training on the vertical jump and on the ultrasound measures of the quadriceps in school children.

2. Method

2.1. Sample

All the children registered in a football sports initiation school of Medellín (Colombia) were invited to participate in the study. The final sample consisted of 37 children, who were between 7 and 10 years old (8.2±0.9 years).The following exclusion criteria were established: cardiovascular or metabolic disease, musculoskeletal injuries, attendance to less than 80% of the sessions and Tanner's self-reported sexual maturation stage different from 1 [7]. All children signed an informed assent, and their parents signed an informed consent. The study protocol was approved by the Ethics Committee of the Jaime Isaza Cadavid Colombian Polytechnic. The participants were divided into 3 age groups **(see Table 1).**

Table 1: Characteristics of the participants (Mean and Standard Deviation).

	n	Age (decimal years)		Weight (Kg)		Height (cm)		BMI (Kg/m²)		% fat	
		2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
G7	17	7.36 ±0.33	8.18 ±0.34	26.65 ±4.55	28.65 ±4.70	124.21 ±4.49	129.72 ±4.02	17.25 ±2.67	17.00 ±2.51	13.91 ±5.74	14.95 ±5.64
G8	11	8.50 ±0.30	9.36 ±0.30	29.25 ±5.30	31.93 ±6.20	131.7 ±3.53	136.36 ±3.17	16.78 ±2.35	17.10 ±2.82	12.98 ±5.91	15.25 ±6.75
G9	9	9.39 ±0.32	10.25 ±0.32	34.33± 7.58	36.51 ±8.58	137.5125 ±6.26	142.25 ±5.99	18.00 ±2.86	17.85 ±2.96	15.25 ±8.47	15.23 ±8.33

The study was conducted through a pre-post, observational, non-randomised design. Thestudy variableswerethefollowing:

Ultrasound Measures: Eco-intensity, pennation angle, muscle thickness and fat thickness were measured using a portable B-model ultrasound device (B-Ultrasonic Diagnostic System, Contec, CMS600P2, Republic of China). A linear transducer (gain: 58, frequency: 7.5 MHz; depth: 6 cm) was placed perpendicular to the skin and covered with enough water-soluble ultrasound gel to prevent the compression of the dermal surface. The participants were evaluated in supine position, after at least 5 minutes of rest and without performing any previous vigorous physical exercise that day. The ultrasound image was obtained in the middle point of a straight line between the anterior superior iliac spine and the upper pole of the right patella [8].Two longitudinal and two cross-sectional images were captured. The frozen image was digitalised and subsequently analysed using the Image J free software (National Institute of Health, USA, version IJ 1.46). A rectangular region of interest was selected from the rectus femoris, vast intermediate and subcutaneous fatty tissue, excluding the fascia and bone tissue, and including as much muscle tissue as possible. In each cross-sectional image, the eco-intensity (EI)and thickness of both the rectus femoris and vast intermediate were evaluated. The two values obtained from the frozen cross-sectional images were averaged to obtain the eco-intensity of each muscle. The pennation angle of the rectus femoris was measured in the two longitudinal images, and the mean value was used for the statistical analysis. All the ultrasound images were obtained by the same researcher. Eco-intensity was determined by gray-scale analysis using the histogram function in ImageJ (National Institute of Health, USA, version IJ 1.46r) [9]. The EI of the region of interest was expressed in values between 0 and 255 (0: black; 255: white).For internal control, the EI of the fatty tissue was used as a reference parameter; thus, the EI of the rectus femoris (Dif1) and vast intermediate (Dif2) and the mean eco-intensity of both muscles (Dif3) were subtracted from this reference parameter [10]. Muscle thickness was determined as the distance between the superficial and deep aponeurosisof the rectus femoris and between the aponeurosis and periosteum of the vast intermediate. The total thickness of the quadriceps was obtained from the sum of the muscle thickness values of both muscles. Between measurements, the children were allowed to move and the transducer was placed again to capture the image. The coefficient of variation of two measures at different time points, on the same day, for 10 individuals was 5.0% and 0.4% for thickness and EI, respectively.

Explosive Strength: Explosive strength was measured by CMJ and RJ. The participants carried out the CMJ twice, and the best jump was used for the statistical analysis. After two minutes of rest, they conducted the RJ, which consisted in consecutive CMJs for 15 seconds. The children were verbally and continually stimulated. The jumps were measured on an AXON JUMP® mat (Axon Bioengeniería Deportiva, Buenos Aires, Argentina) using the Axon Jump 4.0 software, which measured the flight time and, additionally, the contact time in the RJ test. In all the jumps, the participants were required to keep "their hands on their waists". RJ was carried out to calculate the mean power (MP= g2*Tf *15/4n(15-Tf)) and the FT fibre distribution percentage (%FT = 48.31+(g2*Tf *15)/1.04n (15-Tf) (11).CMJ power was obtained using the Sayers formula (Power CMJ(W)=(51.9*height CMJ(cm))+(48.9*body weight(Kg))-2007) [12].

Anthropometric Data: Body weight and height were measured with the participants wearing shorts and no shoes. Body fat percentage was estimated according to Lohman's skinfold formula, measured in two places: the triceps and the subscapular area [13].

3. Procedure

All participants visited the laboratory of the Jaime Isaza Cadavid Colombian Polytechnic (Medellín, Colombia) in November 2017 and then, for the second time, in September 2018, to record the anthropometric measurements: body weight, height and fat percentage. Subsequently, the ultrasound of the right quadriceps was conducted, followed by a brief standardised warm-up, which included the execution of CMJ to allow the participants to familiarize with this specific movement. Then, two CMJs were performed, selecting the best of them in each participant for the statistical analysis. Next, in a single attempt, the participants carried out multiple CMJs for fifteen seconds (RJ). With the information obtained from both jumps (i.e., CMJ and RJ), we calculated the power of the vertical jump (CMJ), the average power of the repeated jumps and the proportion of fast twitch fibres (RJ).

The participants trained 3 times per week (Tuesday, Thursday and Saturday) for ten months, with a duration of 120 minutes per session. The structure of the training session comprised physical, technical and tactical contents from an integral perspective, applied to specific game situations. The training sessions were divided into 8 blocks: 1) stretching, proprioception and core stability (5%), 2) strength (5%), 3) speed (5%), 4) aerobic resistance (5%), 5) general technique (10%), 6) specific technique (20%), 7) sectorial football (25%), and 8) integrated competitive football (25%).

4. Statistical Analysis

In order to facilitate the analysis and the presentation of the results, the variables were organised into three groups. The first group (*Thickness*) includes muscle thickness and pennation angle measured by ultrasound. The second group (*Eco-intensity*) includes the measures of muscle and fatty tissue eco-intensity. The third group (*Functional*) includes the measures of the jumps.

The statistical analysis was performed using the R 3.5.1 software. For each age group (G7=under 8 years, G8=8 years old, G9=9 years old or older), we carried out the tables of means in 2017 and 2018, normality tests and the corresponding hypothesis tests for the difference of means for dependent data (T-test or Mann-Whitney).The non-parametric Mann-Whitney test for paired data was applied for those variables in which normality was not met.The statistical significance level was set at $\alpha=0.05$.

5. Results

The obtained results **(Table2)** show that the rectus femoris and total thickness of the quadriceps increased significantly in the three groups (p=0.0003-0.0076) **(Figure 1).** The thickness of the vast intermediate increased significantly in G7 and G8 (p =0.0359 - 0.0179, respectively).

The pennation angle of the rectus femoris increased significantly only in G9 (p= 0.0303) **(Figure 2)**. The eco-intensity showed significant changes in G9 (EIRF, p=0.0214; EIVI p=0.0347; Dif2 p=0.0422; Dif3 p= 0.0390) **(Figure 3)**. Regarding the variable "jump", significant improvements were only obtained in vertical jump power (PCMJ) in G7 (p=0.0018) **(Figure 4).**

Table 2: Ultrasound and functional variables.

Thickness	**RFT(mm)**		**VIT(mm)**		**TT(mm)**		**SFT (mm)**		**RFPA (°)**			
Mean G7 2017	16.40	2.05	11.08	2.61	27.48	4.01	5.69	2.71	28.74	15.55		
Mean G7 2018	18.77	2.52	12.08	2.78	30.85	4.17	6.29	2.89	32.04	14.15		
Difference	-2.38	***	-0.99	*	-3.37	***	-0.60		-3.30			
Eco-intensity	EIRF		EIVI		EISF		Dif1		Dif2		Dif3	
Mean G7 2017	128.04	11.62	119.65	14.87	150.49	13.39	22.45	12.99	30.84	18.01	26.64	13.73
Mean G7 2018	128.73	5.88	112.33	15.22	148.47	8.28	19.74	10.91	36.14	16.97	27.94	11.95
Difference	-0.69		7.32		2.02		2.71		-5.30		-1.29	
Functional	CMJ (cm)		PCMJ(W)		FT(%)		PM15(W)					
Mean G7 2017	19.87	3.10	473.43	191.22	8.16	9.87	14.68	2.57				
Mean G7 2018	21.49	3.70	630.05	227.80	7.72	6.35	14.57	1.65				
Difference	-1.62		-156.61	**	0.44		0.11					
Thickness	RFT(mm)		VIT(mm)		TT(mm)		SFT(mm)		RFPA (°)			
Mean G8 2017	17.33	2.54	10.61	1.98	27.94	2.61	5.35	2.28	22.84	13.60		
Mean G8 2018	19.14	2.82	11.82	2.44	30.97	3.31	6.53	3.19	22.48	8.33		
Difference	-1.81	***	-1.21	*	-3.02	***	-1.18		0.35			
Eco-intensity	EIRF		EIVI		EISF		Dif1		Dif2		Dif3	
Mean G8 2017	134.13	9.18	128.57	10.84	152.80	11.01	18.67	14.30	24.23	15.38	21.45	12.74
Mean G8 2018	130.53	9.24	123.34	9.56	147.62	11.38	17.10	13.73	24.28	8.86	20.69	9.20
Difference	3.60		5.22		5.17	*	1.57		-0.05		0.76	
Functional	CMJ(cm)		PCMJ(W)		FT(%)		PM15(W)					
Mean G8 2017	20.51	3.55	597.55	171.34	7.31	12.96	14.46	3.37				
Mean G8 2018	20.12	2.94	668.62	204.25	5.43	5.11	13.97	1.33				
Difference	0.39		-71.07		1.88		0.49					
Thickness	RFT(mm)		VIT(mm)		TT(mm)		SFT(mm)		RFPA(°)			
Mean G9 2017	19.13	3.66	12.11	1.57	31.24	3.74	6.02	3.55	28.77	12.69		
Mean G9 2018	21.19	3.59	13.17	1.98	34.36	4.74	6.53	4.27	37.23	13.82		

Difference	-2.06	***	-1.06		-3.12	**	-0.51		-8.47	*		
Eco-intensity	EIRF		EIVI		EISF		Dif1		Dif2		Dif3	
Mean G9 2017	132.56	4.96	119.91	13.09	151.84	11.55	19.29	12.63	31.93	14.46	25.61	11.69
Mean G9 2018	126.19	8.98	111.78	14.88	152.62	13.94	26.43	15.29	40.84	14.97	33.63	13.47
Difference	6.37	*	8.13	*	-0.78		-7.14		-8.91	*	-8.02	*
Functional	CMJ(cm)		PCMJ(W)		FT(%)		MP15(W)					
Mean G9 2017	25.29	1.41	1031.39	268.63	16.63	8.08	16.89	2.10				
Mean G9 2018	25.45	3.97	1115.02	226.97	14.66	7.30	16.37	1.90				

Mean and standard deviation. *p<0.05, **p<0.01. RFT (Rectus Femoris Thickness), VIT(Vast Intermediate Thickness), TT(Total Thickness), SFT (Subcutaneous Fat Thickness), RFPA (Rectus Femoris Pennation Angle), EIRF (Eco-intensity Rectus Femoris), EIVI (Eco-intensity Vastus Intermediate), EISF (Eco-intensity Subcutaneous Fat), Dif1(EISF-EIRF), Dif2(EISF-EIVI),Dif3(EISF-((EIRF+EIVI)/2), CMJ(Countermovement Jump), PCMJ(Countermovement Jump Power), FT (% of Fast-twitch Fibres), MP15(Repeated Jumps Mean Power).

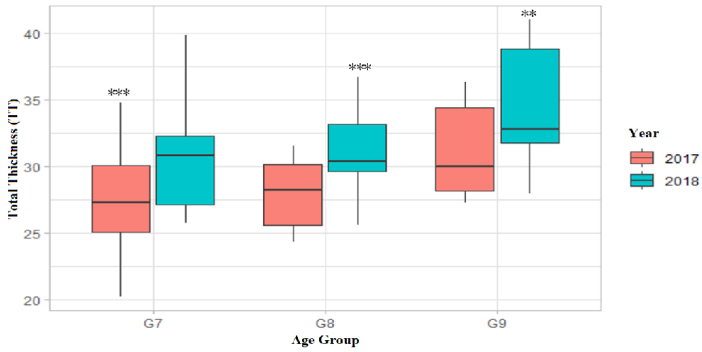

Figure 1: Total thicknessby age group and year.

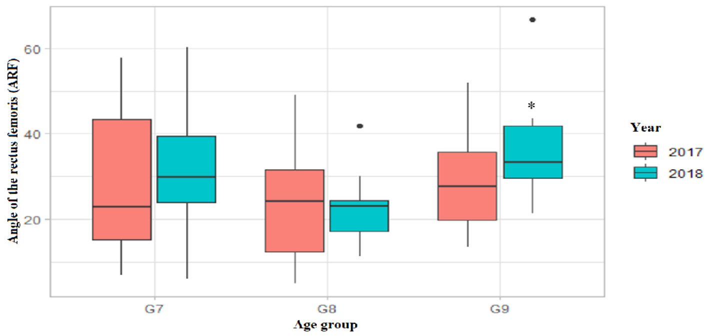

Figure 2: Rectus femoris angle by age group and year.

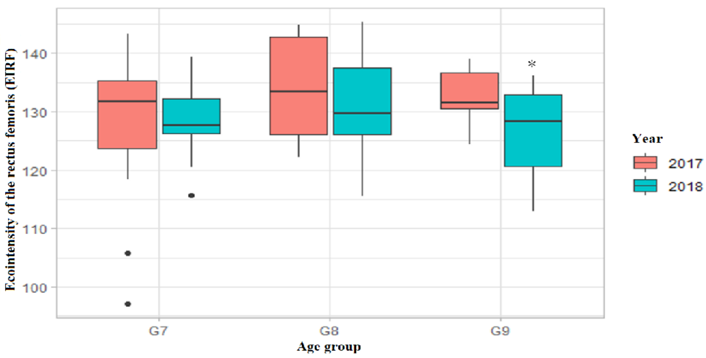

Figure 3: Rectus femoris angle by age group and year.

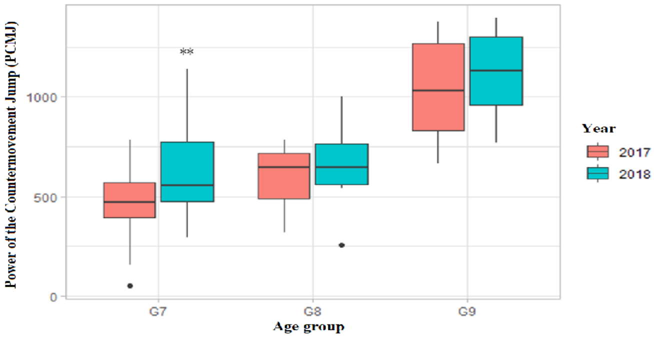

Figure 4: PCMJ by age group and year.

6. Discussion

Metabolic power increases significantly at the age of 6 to 12 years, when the levels of testosterone remain unaltered [14]. Anaerobicmetabolism can be evaluated through the jump action [6].In this sense, O'Brien et al. found a strong correlation in a multi-joint movement, with other muscles involved, between jump power and the muscle volume of the femoral quadriceps [15]. The present study evaluated jump power through CMJ, which improved significantly in one of the three study groups.G8 and G9 showed no significant differences, whereas G7 did show significant differences, probably due to the larger number of participants in the latter with respect to G8 and G9.

There are few studies conducted in similar contexts that allow comparing the results obtained in the present work. A study performed in Turkey with children aged between 0 and 12 years reported normal values in children, including the ages of the population analysed in the present study, i.e., 7-8, 8-9 and 9-10 years [16].In the mentioned study, muscle thickness was practically similar in the groups of 7-8 and 8-9 years (19.7±3.5mm and 19.7 ±3.4 mm, respectively), with the only difference being that the analysed population consisted of non-athlete healthy children. The comparison of muscle thickness with the results of our study, for these age intervals, showed significant differences in the three groups. In this sense, the pennation angle presented a significant difference only in G9. The increase in pennation angle is related to the increase in muscle thickness, which was significant enough to modify it only in this group. It is not possible to compare the means, since the measures were recorded in different anatomical points; however, the increase obtained in the three groups seems to suggest a positive effect of the football training applied to the participants.

In a longitudinal study, Jacobs et al. (2013) evaluated several muscles of 25 healthy children aged between 0 and 12 years with ultrasound, including the quadriceps, with these three parameters: muscle thickness, eco-intensity and muscle strength. The mentioned authors concluded that these parameters were influenced by changes in body weight, height and age, although this influence only had relevant clinical changes in muscle thickness and strength, since eco-intensity was minimal in the analysed healthy children [17]. In the present study, there were changes in muscle thickness, as well as in the vertical jump; however, unlike the mentioned study, our work found significant changes of EI in G9 (i.e., 9-10 years).Eco-intensity is a parameter used to evaluate muscle quality. Lower eco-intensity is related to lower fat content and greater levels of glycogen and contractile proteins [8,18,19].Several studies consider that eco-intensity in children does not change with normal growth, although such studies have been conducted in non-athlete healthy children [20–22].This is the group (G9) that also presented an increase in muscle thickness and a decrease in eco-intensity. However, although there was an increase in vertical jump power, such difference was not statistically significant, which could be due to the small number of participants in this age group. It is worth highlighting that the analysed ultrasound variables increased significantly in this group, which corresponds to the concept of the clear sexual differences that emerge at around the age of 10 years, when boys clearly surpass girls (9.4±0.316 years in the first evaluation, 10.3±0.316 years in the second evaluation).This difference could be due to improvements in the measures of the quadriceps of the children analysed in our study.

The obtained results suggest that regular training, involving a specific orientation, could generate significant changes in muscle quality, and that these changes could be determined through ultrasound evaluation. In this way, in addition to improving muscle power through hypertrophy and nerve maturation, training could have an impact on muscle quality, in a population in which androgens are not substantially secreted yet, thus allowing its evaluation through US.

7. Conclusions

Significant changes in the quantitative ultrasound of the quadriceps, such as the increase in muscle thickness and pennation angle, and the improvement of muscle quality measured by eco-intensity, along with neurological maturation, are related to the improvement of the vertical jump in school children who train regularly in an intermittent sport such as football. All these changes took place at around 10 years of age.

8. References

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