









# Neuromuscular response of young athletes during plyometric and sprint exercises

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## ABSTRACT

The objective was to analyse the neuromuscular response during jumping and sprint exercises in young athletes and adults. Young athletes were divided into 2 groups: indoor soccer (SOC, n = 12) and rugby (RUG, n = 12) and adults were physical education students (PE, n = 12). Sport groups were trained systematically for their sport for 5 years and performed resistance training at least for 2 years. Neuromuscular response was evaluated using a vertical jump test (CMJA), 15-meter sprint test (SPRI) and a rebound test at 3HZ (REB). Force and electromyography were measured during all tests. Leg stiffness (Kvert), rate of force development (RFD) and muscle activation were calculated and analysed. Pre activation and contact EMG were measured for all tests. EMG signal was normalized by CMJA. There were no differences in maturation level between young sport groups as shown by Mirwald's formula ( $p = .897$ ). Significant differences were found in favour of RUG vs SOC during CMJA ( $p = .029$ ). For SPRI and REB, there were no statistical differences between groups for RFD ( $p = .585$ ) and ( $p = .056$ ). Kvert showed no group differences among CMJA ( $p = .396$ ), SPRI ( $p = .329$ ) and REB ( $p = .429$ ). It is concluded that a systematic training in young athletes allows the accelerated development of neuromuscular performance.

**Keywords:** Health, Sports science, Boys, Electromyography, Muscle stiffness, Rate of force development, Running acceleration, Hopping.

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## INTRODUCTION

Muscle activation is decisive for performance in explosive ballistic exercises such as plyometrics and sprinting (Cappa & Behm, 2013; Kyröläinen et al., 2007). Generally, during these actions that project the body in the air, 3 time periods are analysed: pre-activation, eccentric phase, and concentric phase. A significant muscle activation can result in muscle stiffness as calculated using the applied force data (Brughelli & Cronin, 2008). It has been shown that prepubescent subjects have a lower activation during plyometric exercises compared to adults (Lazaridis, 2010). Children have not fully developed the ability to activate muscle-tendinous structures during the eccentric phase of stretch shortening cycles as seen in plyometric continuous jumps or sprints (Hoffren et al., 2011; Ishikawa, 2005).

In prepubescent subjects, the neural system is still in development for the eccentric muscle contraction phase. During linear sprinting, children (ages 10 to 12 years) generate a higher level of co-contraction compared to those 15 to 16 years of age who have more training experience (Frost et al., 1997). This unwanted muscle activation decreases performance. As children continue to train and mature, they increase their capacity for muscle activation. In this process, children reach a maturing development of pubic hair of Tanner 5, where they are considered young adults (Malina & Rogol, 2011). However, these athletes have not finished adapting physiologically and there is little information on the completion of the physiological processes that link them to adulthood.

In adult athletes, a higher level of pre-activation is generated as the running speed is increased (Kuitunen et al., 2002) and it is reduced as fatigue sets in (Girard et al., 2011). No evidence has been found that this manifestation of muscle contraction is the same in subjects of fast growth age undergoing systematic training during this period of transition from puberty to adulthood.

During the neurological/muscle adaptation of children and young people, maturation plays a fundamental role and may partly explain the importance of the physiological changes. It was found that jump and resistance exercises are an important stimulus during the period leading up to the peak of maximum growth in determining speed and that these types of work increase jump and sprint performance (Radnor et al., 2017).

Regarding maturation and its relationship with performance, Amonette et al. (2014) showed that performance increases are attenuated when subjects reach the age of ~17 in team sports. The author found that 17-year-old players from an elite football academy have the same performance in a sprint and vertical jumping test as 16-year-old players. In contrast, it has been observed that performance can continue to increase until 20 years of age in high performance soccer players belonging to an elite level team (Salinero et al., 2019). They found that both during the slalom sprint, fatigue tolerance and the vertical jump, 18–19-year-old players performed at a higher level than their 17-year-old peers. These differences are based on the specificity of the workouts and of the neuromuscular evaluation.

Furthermore, it was demonstrated that a specific ballistic training stimulus in young men and women increased neuromuscular performance via vertical jumping and sprint tests (Hammet, 2003). The data corroborate the principle of load specificity since the subjects performed ballistic sprint exercises with elastic overload.

Thus, the aim of this study was to determine if young athletes, who train systematically, develop muscle stiffness (STIF) and a rate of force development (RFD) similar to that of active adults during rebound and sprint exercises.

## METHODS

### **Participants**

A group of young athletes at the regional level and a group of adult physical education students were evaluated. Athletes trained at least 5 times a week including the competition. The students had the physical activity load imposed by the curriculum of study of the career. Subjects attended the laboratory to be evaluated on one occasion and the session lasted approximately 2 hours.

Thirty-six male participants (12 physical education students (PE) (age  $22.3 \pm 1.96$ , mass  $75.3 \pm 9.22$  kg and height  $177.9 \pm 6.98$  cm), 12 soccer players (SOC) (age  $16.6 \pm 0.84$ , mass  $63.7 \pm 10.33$  kg and height  $168.2 \pm 5.5$  cm) and 12 rugby players (RUG) (age  $15.6 \pm 0.41$  years, mass  $77.2 \pm 11.3$  kg and height  $173.2 \pm 7.03$  cm) were evaluated. The inclusion criteria for the adults PE students were physically active, not perform competitive sports practice, and have not incapacitating injuries in the last 8 months; for the sample of athletes were: train at least 5 or more times per week, have at least 5 years of uninterrupted training, are accustomed to sprints and high intensity jumps and have not incapacitating injuries in the last 8 months. To analyse the degree of maturation of young athletes, Mirwald's formula was applied to know how much time had elapsed after surpassing the peak of maximum growth speed (Mirwald et al., 2002).

### **Procedures**

The following test were administrated: a maximum vertical jump with the use of arms (CMJA), a maximum 15 m sprint (SPRI) and a rebound test at a frequency of 3 Hz (REB). A force platform and surface electromyography were used for all tests. After a standardized warm up that included jogging, active flexibility and sub maximum and maximum efforts of each test, 2 attempts were recorded. If the difference in data exceeded 5 per cent, a third attempt was made, and the statistical median was calculated. For the speed test, a radar (ATS II, Stalker, Applied Concepts, TX, USA), a portable electromyographic system (PLUX - Wireless Biosignals S.A. Lisboa, Portugal) and a force platform (PS2142 2-axis, PASCO Scientific Inc, CA, USA) were used with a sampling rate of 1000 Hz. A smartphone with high-speed camera iPhone 8 plus at 240 Hz was used to record the sprint test. In all evaluation, the rate of force development (RFD) and muscle stiffness ( $K_{\text{vert}}$ ) were calculated.

All evaluations were carried out between 14.00 and 18.00 hr with temperatures between 23 and 26 degrees C and humidity between 35 and 50%. The anthropometric variables of body mass (kg), standing height (cm) and sitting height (cm) were evaluated. The measures were taken by a researcher accredited by the International Society for the Advancement of Kinanthropometry (ISAK), following its rules and protocols. A Seca 220® (Birmingham, UK) was used to measure the height and mass.

Force was evaluated during a CMJA test by using a force platform. The test consists of performing a vertical jump with maximum counter movement using the arm impulse. SPRI test consisted of running 15 meters at maximum speed. The test started from the stand up and static position. The athlete covered the distance at maximum speed. The starting technique was chosen freely by each participant without knowing at any time the rest. A radar was used which was positioned 10 m behind the subject at hip height. In addition, a force platform was available in the first step support of the sprint.

The rebound test consisted of continuous bipodal jumps on the force platform at a frequency of 3 Hz. During the test a digital metronome was used to follow the cadence of execution. Subjects were asked to minimize support and flight time. In these rebounds there is a very important work of the ankle muscles and a minimization of the use of those of the knee. During all the described tests, the electromyographic activity of the vastus lateralis (VL), the medial gastrocnemius (MG) and the external lateral hamstrings (LH) were analysed.

To record the electromyography, pre-gelled Ag/AgCl surface electrodes (3M) were used and were arranged according to the indications of SENIAM standards (Stegeman et al., 2007). The raw electromyography signal was recorded at 1000 Hz with Opensignals (r)evolution software and then conditioned using a MATLAB software by filtering the signal with a 6<sup>o</sup> order Butterworth and a 50 Hz cut-off frequency. Finally, root mean square (RMS) was calculated and the mean of each group was recorded in each exercise. To all tests muscle activation was analysed during contact time. While for SPRI and REB pre activation was measured which was considered 100 msec before the feet touch the floor. The electromyographic signal was normalized by the activity generated during the CMJA test as recommended by Kyrolainen et al. who showed that ballistic actions such as sprint have levels much higher than maximum isometric actions (Kyröläinen et al., 2007).

### **Data analysis**

During the CMJA test the following variables were measured: peak force (PF in N), contact time (CT in ms) and flight time (FT in ms). The relative peak force (FPN in  $N \cdot kg^{-1}$ ), rate of force development (RFD in  $N \cdot s^{-1}$ ), mechanical power (POT in W) and vertical stiffness ( $K_{vert}$  in  $kN \cdot m^{-1}$ ) were calculated. For mechanical power was used the Sayers formula (Sayers et al., 1999).

During SPRI test velocity was measured at 5, 10 and 15 m ( $m \cdot s^{-1}$ ) through the radar with a sampling rate of 47 Hz. Peak force (N) was also recorded with a force platform during the first step support of the sprint and contact time (ms). Support time of the third step of the sprint was calculated with the software tools Kinovea® v.0.9.4. During the REB test, average peak force (N) of 3 supports that met the premise of holding 3 Hz during the execution was recorded. To calculate RFD the peak force was divided by the time used to reach it. To  $K_{vert}$ , body mass was multiplied by the natural frequency of oscillation of the force (values above body mass), according to McMahon (McMahon & Cheng, 1990).

### **Statistical treatment**

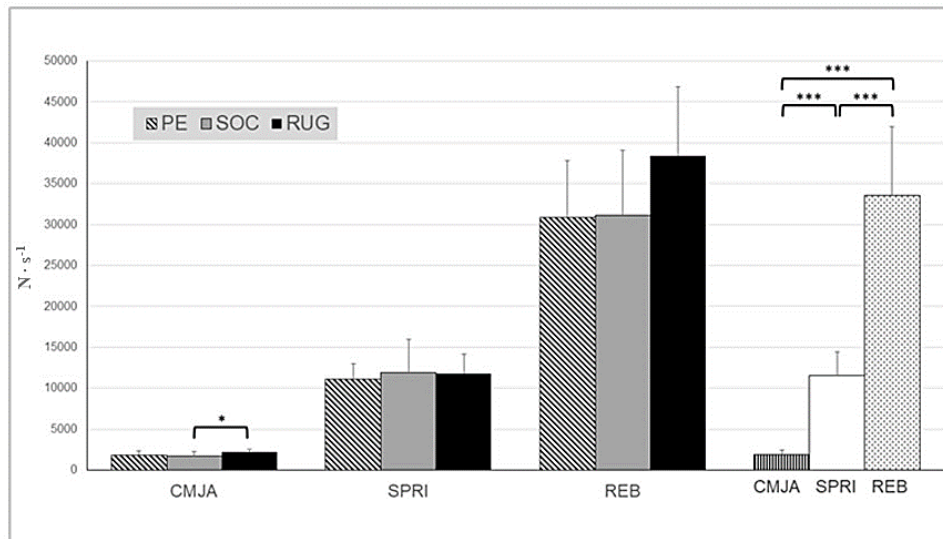
The statistical analysis was performed with JASP - Amsterdam (Version 0.16.1) and Microsoft Office Excel 365 (Microsoft® Software). Normality test was applied to all variables with Shapiro-Wilk. A transformation was used in those variables that did not meet a normal distribution. The results are presented as standard mean and deviations. Variance analysis (ANOVA of repeated measures) was applied for the comparison of group averages and types of exercise. The following levels of significance were used to analyse the differences: \* $p < .05$ ; \*\* $p < .01$ ; \*\*\* $p < .001$ . Finally, a Bonferroni post hoc analysis was applied to detect where the differences were.

## **RESULTS**

Maturation level of the two sports groups was analysed. This was done to know if samples were similar. The results of the Mirwald method revealed that there was no difference in the degree of maturation (SOC  $2.148 \pm 0.6$  and RUG  $1.985 \pm 0.633$  years,  $t = 0.445$ ,  $p = .897$ ). Then, RFD and  $K_{vert}$  were analysed in ballistic exercises comparing young athletes undergoing systematic training and active adult subjects. Figure 1 shows the results of RFD, which is a variable representing the power of the movements. Significant differences were

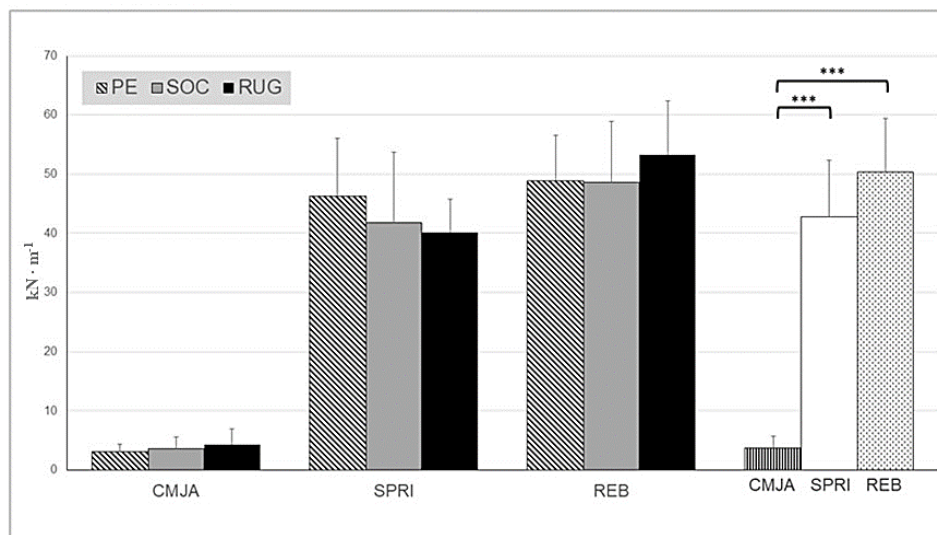
found in favour of RUG vs SOC in CMJA exercise ( $F = 4.253$ ,  $p = .029$ ,  $\eta^2 = 0.298$ ,  $p_{Mauchly} = .162$ , 95% CI: -0.578, -0.027,  $t = -2.873$ ;  $p_{bonf} = .028$ ). Results for the RFD during the SPRI test showed no statistically significant differences ( $p = .585$ ). Similarly, when the results for REB were analysed, no differences were found ( $p = .056$ ).

Regarding the analysis of the exercises, the following differences were found: RFD was greater for SPRI vs CMJA ( $F (X^2) = 66.0$ ,  $p < .001$ , T-Stat = 4.062,  $p_{bonf} < .001$ ). Meanwhile, REB test was higher than CMJA (T-Stat = 8.124,  $p_{bonf} < .001$ ) and SPRI (T-Stat = 4.062,  $p_{bonf} < .001$ ) (see Figure 1).



Note. PE = Physical Education, SOC = Soccer, RUG= Rugby. CMJA = Counter Movement Jump with Arms. SPRI = 15 m sprint, REB = Rebounds at 3 Hz. \* ( $p < .05$ ) \*\*\* ( $p < .001$ ).

Figure 1. Rate of force development (RFD).



Note. PE = Physical Education, SOC = Soccer, RUG = Rugby. CMJA = Countermovement Jump with Arms, SPRI = 15 m sprint, REB = rebounds at 3 Hz. \*\*\*  $p < .001$ .

Figure 2. Vertical stiffness (KvERT).



Figure 2 shows the results of the  $K_{vert}$  in the 3 groups and the 3 exercises. Regarding the group analysis, no significant differences were found in CMJA ( $p = .396$ ), SPRI ( $p = .329$ ) or for REB ( $p = .429$ ). However, there is a big difference when analysing type of exercise. SPRI test was higher than CMJA ( $F(X^2) = 59.556$ ,  $p < .001$ ,  $T\text{-Stat} = 5.185$ ,  $p_{bonf} < .001$ ), while REB was higher than CMJA ( $T\text{-Stat} = 7.542$ ,  $p_{bonf} < .001$ ) (see Figure 2).

When the other performance variables were analysed, it was found that reached height during CMJA (variable that is frequently used for training control), was not different between groups ( $p = .211$ ). By conducting a deeper analysis, we can observe that when body mass is involved as a variable that influences the height of the jump and the relative mechanical power is calculated, a difference is observed in favour of SOC athletes compared to the other groups ( $F = 4.443$ ,  $p = .024$ ,  $\eta^2 = 0.288$ ,  $p_{Mauchly} = .499$ , 95% CI: 0.579, 9.920,  $t = 2.913$ ,  $p_{bonf} = .024$ ) (see Table 1).

Table 1. Plyometric and sprint performance.

	PE ( $\bar{x} \pm SD$ )	SOC ( $\bar{x} \pm SD$ )	RUG ( $\bar{x} \pm SD$ )
CMJA Height (cm)	41.90 $\pm$ 5.6	43.20 $\pm$ 7.6	38.6 $\pm$ 4.90
CMJA Relative Power ( $W \cdot kg^{-1}$ )	37.71 $\pm$ 3.83	41.33 $\pm$ 6.08*	36.08 $\pm$ 3.18
SPRI 5 ( $m \cdot s^{-1}$ )	5.61 $\pm$ 0.23	5.60 $\pm$ 0.26	5.65 $\pm$ 0.31
SPRI 10 ( $m \cdot s^{-1}$ )	6.79 $\pm$ 0.24	6.86 $\pm$ 0.25	6.89 $\pm$ 0.40
SPRI 15 ( $m \cdot s^{-1}$ )	7.37 $\pm$ 0.27	7.52 $\pm$ 0.25	7.50 $\pm$ 0.50
SPRI Relative Horizontal Peak Force ( $N \cdot kg^{-1}$ )	5.77 $\pm$ 1.12	5.83 $\pm$ 0.90	5.53 $\pm$ 1.12
SPRI Contact Time (ms)	212.67 $\pm$ 22.38	201.83 $\pm$ 16.82	217.9 $\pm$ 23.34
REB Relative Peak Force ( $N \cdot kg^{-1}$ )	34.10 $\pm$ 3.81	38.60 $\pm$ 4.78	37.1 $\pm$ 3.55
REB Contact Time (ms)	195.86 $\pm$ 46.92	179.69 $\pm$ 16.66	177.2 $\pm$ 20.68

Note: PE = Physical Education, SOC = Soccer, RUG = Rugby, CMJA = Countermovement Jump with Arms, SPRI = Sprint, REB = Rebounds at 3 Hz. \* ( $p < .05$ ) SOC vs PE and RUG.

Regarding velocity during SPRI test, no significant differences were found between groups. This was observed at all split distances analysed (5m,  $p = .768$ ; 10m,  $p = .467$  and 15m,  $p = .422$ ). When the normalized horizontal peak force was analysed, no significant differences were found either ( $p = .805$ ). Regarding the analysis of contact time of the first SPRI step, no significant differences were found ( $p = .276$ ). When REB test results were analysed, no differences were found in the vertical force peak normalised for mass ( $p = .062$ ) nor during contact time ( $p = .305$ ).

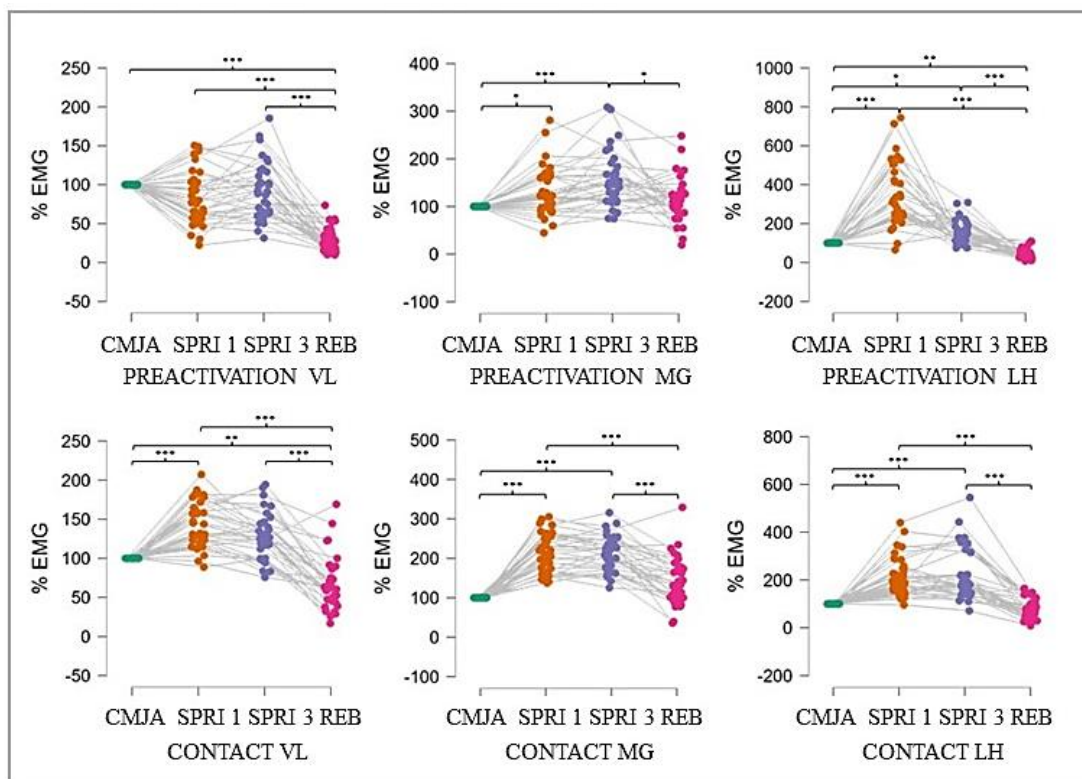
Results of muscle activation are showed in Table 2. The following differences were observed in MG in the first contact of the sprint ( $F(X^2) = 11.231$ ,  $p = .004$ ,  $\eta^2 = 0.224$  in favour of SOC vs PE;  $T\text{-stat} = 3.334$ ;  $p_{bonf} = .008$ ). During pre-activation of LH in the sprint ( $F = 4.784$ ,  $p = .019$ ,  $\eta^2 = 0.303$ , in favour of SOC vs PE;  $t = -3.074$ , 95% CI: -1.05, -0.086,  $p_{bonf} = .017$ ). Besides for MG during REB ( $F = 4.825$ ,  $p = .017$ ,  $\eta^2 = 0.287$ ,  $p_{Mauchly} = .751$  in favour of SOC vs PE;  $t = -2.963$ , 95% CI: -90.59, -6.376,  $p_{bonf} = .02$ ). During the contact MG ( $F = 17.372$ ,  $p < .001$ ,  $\eta^2 = 0.591$ ,  $p_{Mauchly} = .146$  in favour of SOC vs PE; 95% CI: -130.981, -45.484,  $t = -5.312$ ,  $p_{bonf} < .001$ ; in favour of SOC vs Rugby, 95% CI: 80.864, 38.116,  $t = 4.868$ ,  $p_{bonf} < .001$ ). No significant differences were found when comparing the other EMG variables ( $p > .05$ ).

To identify more closely the muscle activation of all groups together during the different tests, Figure 3 was configured. The upper part shows the muscle pre activation of all subjects normalized by activation during CMJA, which is represented as the initial 100%. The first (SPRI 1) and third step (SPRI 3) of the sprint and rebounds are shown in the figure. On the other hand, the lower part of the figure exhibits muscle activation during contact for the same tests.

Table 2. Muscle activation during sprint and rebounds.

Muscle	CMJA	SPRI 1 PRE	SPRI 1 CON	SPRI 3 PRE	SPRI 3 CON	REB PRE	REB CON
		( $\bar{x} \pm SD$ )	( $\bar{x} \pm SD$ )	( $\bar{x} \pm SD$ )	( $\bar{x} \pm SD$ )	( $\bar{x} \pm SD$ )	( $\bar{x} \pm SD$ )
<b>PE</b>							
VL	100%	66.9 ± 30.05	136.3 ± 50.00	82.5 ± 35.36	128.0 ± 19.08	33.0 ± 18.59	71.2 ± 42.21
MG	100%	160.9 ± 114.37	240.9 ± 130.70	226.6 ± 208.60	239.2 ± 123.58	93.3 ± 47.03	107.5 ± 49.37
LH	100%	297.0 ± 178.73	219.7 ± 88.55	315.5 ± 193.87	216.6 ± 133.14	51.1 ± 32.86	79.3 ± 43.51
<b>SOC</b>							
VL	100%	87.7 ± 26.07	148.9 ± 27.38	95.5 ± 23.23	131.9 ± 35.15	29.6 ± 14.75	75.3 ± 28.91
MG	100%	148.6 ± 68.37	258.1 ± 36.01 <sup>a*</sup>	176.1 ± 59.31	235.1 ± 43.80	141.8 ± 52.00 <sup>c**</sup>	195.7 ± 53.69 <sup>d***</sup>
LH	100%	385.7 ± 187.30	203.8 ± 62.13	457.3 ± 234.82 <sup>b*</sup>	235.3 ± 104.96	39.9 ± 20.14	80.0 ± 39.72
<b>RUG</b>							
VL	100%	93.2 ± 6.86	137.2 ± 26.78	105.0 ± 40.80	157.7 ± 113.02	24.0 ± 9.95	47.9 ± 18.62
MG	100%	120.7 ± 33.61	181.8 ± 34.83	124.7 ± 39.21	196.6 ± 41.00	104.4 ± 27.66	114.8 ± 25.17
LH	100%	329.7 ± 88.10	214.1 ± 84.31	357.2 ± 130.11	205.5 ± 72.21	37.1 ± 20.79	68.7 ± 36.09

Note: PE = Physical Education, SOC = Soccer, RUG = Rugby, VL = Vastus Lateralis, MG = Medial Gastrocnemius, LH = Lateral Hamstrings, PRE = Pre activation time; CON = Contact time, CMJA = Countermovement Jump with Arms, SPRI 1 = 1st step in Sprint, SPRI 3 = 3rd step in Sprint, REB= Rebounds at 3 Hz. \* ( $p < .05$ ) \*\* ( $p < .01$ ) \*\*\* ( $p < .001$ ). a\* SOC vs RUG; b\* SOC vs PE; c\*\* SOC vs PE; d\*\*\* SOC vs PE and RUG.



Note. MG = Medial Gastrocnemius, VL = Vastus Lateralis, LH = Lateral Hamstrings, CMJA = Countermovement Jump with Arms, SPRI 1 = 1<sup>st</sup> step in sprint, SPRI 3 = 3<sup>rd</sup> step in phut and REB = rebounds at 3 Hz. CMJA EMG = 100%. \* ( $p < .05$ ) \*\* ( $p < .01$ ) \*\*\* ( $p < .001$ ).

Figure 3. Muscle activation response during exercises.

Results for pre activation showed differences in VL ( $F(X^2) = 64.458$ ,  $p < .001$ ,  $W_{Kendall} = 0.597$ ) in favour of SPRI 1 vs CMJA (T-stat = 2.463,  $p_{holm} = .092$ ); CMJA vs REB (T-stat = 7.298,  $p_{holm} < .001$ ); SPRI 1 vs REB (T-stat = 4.835,  $p_{holm} < .001$ ) and SPRI 3 vs REB (T-stat = 6.477,  $p_{holm} < .001$ ). GM showed ( $F(X^2) = 26.637$ ,

$p < .001$ ,  $W_{\text{Kendall}} = 0.254$ ) in favour of SPRI 1 vs CMJA (T-stat = 3.057,  $p_{\text{holm}} = .017$ ); SPRI 3 vs CMJA (T-stat = 5.049,  $p_{\text{holm}} < .001$ ) and SPRI 3 vs REB (T-stat = 2.965,  $p_{\text{holm}} = .023$ ). LH showed ( $F(X^2) = 82.504$ ,  $p < .001$ ,  $W_{\text{Kendall}} = 0.809$ ) in favour of SPRI 1 vs CMJA (T-stat = 5.389,  $p_{\text{holm}} < .001$ ); SPRI 3 vs CMJA (T-stat = 2.718,  $p_{\text{holm}} = .047$ ); CMJA vs REB (T-stat = 3.233,  $p_{\text{holm}} < .01$ ); SPRI 1 vs REB (T-stat = 8.622,  $p_{\text{holm}} < .001$ ) and SPRI 3 vs REB (T-stat = 5.951,  $p_{\text{holm}} < .001$ ).

During the contact time VL showed ( $F(X^2) = 73.353$ ,  $p < .001$ ,  $W_{\text{Kendall}} = 0.699$ ) in favour of SPRI 1 vs CMJA (T-stat = 4.918,  $p_{\text{holm}} < .001$ ); CMJA vs REB (T-stat = 3.155,  $p_{\text{holm}} = .013$ ); REB vs CMJA (T-stat = 3.202,  $p_{\text{holm}} < .01$ ); SPRI 1 vs REB (T-stat = 8.072,  $p_{\text{holm}} < .001$ ) and SPRI 3 vs REB (T-stat = 5.846,  $p_{\text{holm}} < .001$ ). GM showed ( $F(X^2) = 77.0$ ,  $p < .001$ ,  $W_{\text{Kendall}} = 0.733$ ) in favour of SPRI 1 vs CMJA (T-stat = 7.494,  $p_{\text{holm}} < .001$ ); SPRI 3 vs CMJA (T-stat = 6.754,  $p_{\text{holm}} < .001$ ); SPRI 1 vs REB (T-stat = 5.088,  $p_{\text{holm}} < .001$ ) and SPRI 3 vs REB (T-stat = 4.348,  $p_{\text{holm}} < .001$ ). Finally, LH showed ( $F(X^2) = 80.118$ ,  $p < .001$ ,  $W_{\text{Kendall}} = 0.763$ ) in favour of SPRI 1 vs CMJA (T-stat = 5.42,  $p_{\text{holm}} < .001$ ); SPRI 3 vs CMJA (T-stat = 5.42,  $p_{\text{holm}} < .001$ ); SPRI 1 vs REB (T-stat = 6.995,  $p_{\text{holm}} < .001$ ) and SPRI 3 vs REB (T-stat = 6.995,  $p_{\text{holm}} < .001$ ).

## DISCUSSION

The results of this study reveal the influence of systematic training on the development of neuromuscular characteristics during ballistic exercises. It was found that young people trained at young ages already possess neuromuscular characteristics similar to active adults. Table 1 shows that CMJA and SPRI performance (5, 10 and 15 m) were not different. This shows that the level is similar being adults over 5.5 years older and they have logically already finished their maturation.

Although no significant differences were found in speed and jumps between groups, when the calculated derived variables were analysed, SOC athletes showed a higher horizontal peak force during SPRI. There is good evidence in literature on the influence of horizontal force on sprint performance in adults (Brughelli et al., 2011; Kyröläinen et al., 2007) and in young people (Nagahara et al., 2017). However, this higher level of strength could not contribute to showing a better result in speed, so it could be deduced that the subjects applied a technique during running that did not benefit from this advantage.

For example, they could use a greater angle of tilt to the front during the static sprint start as Kugler showed in his work (Kugler & Janshen, 2010). The author found that the fastest subjects had a greater angle of force application ( $41^\circ$  vs  $38^\circ$ ), meaning that they were more inclined to the front during the first step of the sprint (+7.3%). It is important to note that they did not find differences in the average horizontal force between fast and slow subjects, a situation that explains the importance of the running technique.

The average speed performance for 10 meters of sports groups was  $5,625 \text{ m}\cdot\text{s}^{-1}$ . This is equivalent to covering 10 meters in 1.777 s. Values that are similar to those published by Cunha (1.76 s) for post-puberal SOC players at the provincial level of Brazil (Cunha et al., 2017) and also to a systematic review published by Rumpf, where 34 studies were analysed (Rumpf et al., 2011). In contrast, Gabbett evaluated rugby league players of similar age and found a slightly lower performance (Gabbett, 2006). This could be due to a higher body mass of that sample compared to this work (+4 kg) or that the players' level was from a lower league. Sander published slightly higher values, but for players aged 17 (Sander et al., 2017). It is difficult to make comparisons in this period since many studies do not publish the degree of maturation of the sample. In our research, subjects used the preferred starting technique during the test. Although this technique can influence performance (Frost & Cronin, 2011), there is no evidence that changing the technique trained for a long time can improve or worsen a maximum test.



In terms of performance for CMJA, an average for youth sports groups of 40.9 cm similar to the 50-75 percentile published by Haugen for elite SOC players over 16 years old (Haugen et al., 2014). The performance of this sample is also above SOC of an elite academy (+3.9 cm - 9.5%) (Amonette et al., 2014) although the measurement technique did not use the arms.

### **Muscle stiffness**

Maturation affects performance during SPRI and muscle Kvert is one of the variables that explains this adaptation (Rumpf et al., 2013). The absorption of force during the eccentric phase of the sprint seems to be partly the explanation for the increase in the Kvert, which self-regulates according to the speed of movement (Farley et al., 1991). It is possible that titin plays an important role during the development of this feature (Herzog et al., 2012; Nishikawa et al., 2012). The model proposed by the authors is that titin binds to actin without the need for energy expenditure and a higher level of force (hence stiffness) is generated during shortening stretching cycles.

This phenomenon is more important when using explosive ballistic exercises where the body is projected in the air as in multijumps. The levels of eccentric force are much higher when compared with a jump with countermovement (Cappa & Behm, 2011; Perttunen et al., 2000).

### **Rate of force development**

RFD is used to identify performance on various motor tasks. In general, RFD is higher when it is evaluated during ballistic exercises as a jump over hurdles compared to a long stretch shortening cycle like CMJ (Cappa & Behm, 2013) and also when compared with some isometric actions (Wilson et al., 1995). However, this depends on the method used for its calculation. The RFD of the rebounds in this work has shown to have a very high values and resemble those of the jumps on hurdles. These yields are achieved with very high net strength values and low contact times projecting the body into the air, actions that are very similar to those of competition.

The results of the RFD were similar among the groups and this is due to the training process of the young athletes. Anyway, this variable has a high level of variability in the results depending on the method used for its calculation (Hernández-Davó et al., 2014). RFD showed a significative higher level in rebounds. However, this variable is calculated using vertical force. During the sprint the horizontal force is prioritized. So, it is possible that we may need use this variable to calculate an index that shows more sensitive to this type of test.

### **Muscle activation by group**

When the EMG analysis was performed, SOC showed the highest level of activation in the vertical rebounds and, however, it did not show to be faster during sprint or to reach a higher height during CMJA. This phenomenon could be explained because, to optimize sprint, a higher level of horizontal force should be applied as previously mentioned. This is achieved by braking less and pushing more (Morin, et al., 2015), a situation that is achieved with the application of running technical exercises.

This concept supports the specificity of the movements to improve the sprint published by Barr. The author showed that an increase of 10 kg (+8.25%) in the exercise of hang power clean that represents vertical force during a season, did not allow athletes to increase the speed of a 10 or 40 m sprint (Barr et al., 2014). This supports the idea of the specificity of strength training according to the direction of application of the vector (Cappa D., 2019).

### **Muscle activation by exercise**

EMG results allow us to know when a muscle is activated in certain part of the movement. During pre-activation REB test, thigh muscles (VL and LH) show low activity. Note in Figure 3 that some values are below the activation level during contraction in the CMJA. Remember that CMJA has a very low stiffness behaviour (Cappa & Behm, 2013). MG shows a good activation, and this explains why coaches use high frequency rebounds to develop ankle muscle stiffness which are primarily responsible for leg stiffness (Farley & Morgenroth, 1999). Also, during pre-activation, LH shows very high activity values during SPRI 1 and 3. This is because it is highly requested to break the inertia in the first steps of the sprint and generate an acceleration of approximately  $7 \text{ m}\cdot\text{s}^{-2}$  (Berthoin et al., 2001; Morin, et al., 2015). During the contact (eccentric + concentric phase), a similar low VL and LH activity was observed for the REB test which was to be expected. MG activity was very high even when it was compared with CMJA, and this can be explained by the fact that this type of jump do not have a pre activation activity. As for the GM, a great activation is observed in all the tests, although it decreases slightly in REB because the range of motion of the ankle is lower in this type of exercise compared with a running acceleration.

### **CONCLUSION**

According to the data found in our study, it is concluded that young athletes who undergo systematic training for regional sports do not have neuromuscular differences compared to active adults in ballistic exercises like jumps and sprints. This proves that a training volume of 5 times per week, added to a maximum stimulus such as the rugby and soccer match that includes jumps, sprints, changes of direction, running accelerations, and high-intensity braking, allow the premature development of neuromuscular characteristics when compared to active adults.

### **AUTHOR CONTRIBUTIONS**

All authors have contributed to the recording and analysis of data, as well as to the design of the research and the drafting of the document and conclusions of the work.

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### **DISCLOSURE STATEMENT**

All authors declare that they have no conflict of interest. The experiments reported in this manuscript were conducted in strict accordance with all applicable laws and regulations of Argentina.

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