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Internal load of a repeated sprint protocol in pubertal soccer players exposed to moderate altitude

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Abstract

This study aimed to describe the performance on a repeated sprint test and assess internal load in youth soccer players at an altitude of 2650 meters. Sixty regional-level soccer players (age 14.1±1.7 years) participated in an RSA 7x30m-20" test. The study assessed height, body mass, fat mass, and Peak Height Velocity (PHV). Heart rate (HR) and blood lactate (LA) levels were monitored, and theoretical fatigue was estimated using the Fatigue Index (FI) and percentage decrement score (Sdec%). Descriptive and correlational statistics were employed for data analysis of anthropometry, performance, and internal load. ANOVA was used to compare different indicators across age groups. Across the sample, HR increased from 109±1 to 181±9 bpm during the protocol. LA mmol/L levels rose significantly at various points: pre-test vs. fourth repetition ($t=18.706$, $p<0.001$), fourth repetition vs. post-test ($t=9.115$, $p<0.001$), and pre-test vs. post-test ($t=33.919$, $p<0.001$). Performance results indicated that the 12-year-old group performed lower than other groups ($F=12.261$, $p<0.001$). The study concludes that RSA performance in the 7x30m-20" at 2650 improves with increasing age. LA and estimated fatigue were slightly higher in older participants; however, substantial inter-individual variability was observed in internal load.

Keywords: *youth soccer; heart rate, lactate, repeated sprints, sports performance*

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Introduction

The external load has been extensively studied in soccer (Maughan et al., 2021), showing that the volume of high-intensity running (19.8–25.1 km/h) varies between 335–596 meters (Gualtieri et al., 2023) and maximum speed (> 25.1 km/h) between 96–295 meters in professional competitions (Pons et al., 2021). This fact increases the importance of evaluating and developing the ability to perform repeated sprints

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RSA in players (Gualtieri et al., 2023). RSA tests are performed in the field, executing various sprints interspersed with brief recovery periods (Girard et al., 2011). Currently, various RSA protocols are implemented with differing numbers of repetitions (e.g., 6, 7, or 8), distances (e.g., 10m, 20m, or 30m), and recovery times (e.g., 15s, 20s, or 25s). However, there is no established "Gold Standard" RSA protocol that includes linear or change-of-direction movements, nor one that specifies whether to use a ball (Thurlow et al., 2024; Kyles et al., 2023).

The RSA test is consistently regarded as a specific assessment for soccer players (Castagna et al., 2018). It is dependent on the glycolytic power of the muscles and the phosphagen reserves, which ensure physiological responses (internal load) similar to those experienced during intense game periods. For instance, maximum heart rates (HR) can reach around 187 ± 9 bpm, and mean blood lactate (LA) levels 7.9 ± 0.7 mmol/L (Krustrup et al., 2006), therefore, RSA is also often recognized as a test with ecological validity (Fernández-Da-Silva et al., 2019; Castagna et al., 2018). Also, RSA best sprint and RSA mean are the most used indicators to express the RSA performance (Kyles et al., 2023; Castagna, 2018; Gibson et al., 2017; Padulo et al., 2015), and they are also necessary to estimate theoretical fatigue indicators in RSA protocols such as the fatigue index FI and the percentage decrement score Sdec% (Girard et al., 2011; Bishop et al., 2001).

On the other hand, the altitude at which soccer players compete affects the performance of teams and players (Levine et al., 2008), being a factor that benefits the locals; for this reason, FIFA categorized the altitudes as follows: near to sea level 0-500m, low altitude >500m-2000m, moderate altitude >2000m-3000m, high altitude >3000m-5,500m and extreme altitude +5,500m (Bärtsch et al., 2008). Several studies have analyzed training methods under altitude conditions controlled by hypobaric chambers (Girard et al., 2017; Brocherie et al., 2017). As altitude increases, air pressure changes, leading to what is known as hypoxic work. Under these conditions, the internal load rises during maximum efforts at moderate and high altitudes compared to sea level (Girard et al., 2017; Gore et al., 2008). While indicators such as HR and LA tend to show higher values, sprint performance may improve at high altitudes. However, repeated sprint ability (RSA) generally decreases performance (Girard et al., 2017; Brocherie et al., 2017; Salazar-Martínez et al., 2025).

Studies examining RSA in pre-pubertal and pubertal soccer players typically include participants from the same squad and present the RSA results by a large range of age (Rey et al., 2019; Buchheit and Mendez-Villanueva, 2014). The most frequently explored topic is the effectiveness of training programs in improving performance (Thurlow et al., 2024; Kyles et al., 2023). Examining results by age groups could better explain the performance and internal load of players observed within growth stages. Research on RSA during adolescence at moderate altitude is limited. Therefore, the present study aims to describe the performance in the RSA 7x30m-20" test, as well as the physiological responses of HR and LA in youth soccer players from Bogotá, DC.

Methods

Participants

Sixty soccer players from three clubs in Bogotá, Colombia, participated in this study. All players were acclimatized to altitude, as they reside in the city at an elevation of approximately 2,650 meters above sea level. The assessments were conducted on separate days at each club during regular training sessions. Eligibility criteria included being between 12 and 16 years old, training four days per week, and having authorization from the coach and the club's medical team, with only injury-free players included. All participants regularly competed in official tournaments, trained for 10 to 12 hours per week, and were affiliated with the Bogotá Soccer League. Parents and guardians provided written authorization through an informed consent form, which detailed the study's general aspects, the tests to be conducted, and the data processing in accordance with the ethical principles established in the Declaration of Helsinki. This research was authorized by the clubs involved and approved by the Santo Tomas University Ethics Committee No. 006 of 2024.

Procedures and materials

Chronological age was calculated according to the difference between the assessment date and the date of birth. Basic anthropometry measurements were performed, including height, body mass, and skinfold thickness (triceps-subscapularis). Fat mass was estimated according to the protocol for youth ages proposed by (Slaughter et al., 1988), corresponding to % fat = 1.21*(triceps skinfold + subscapularis skinfold) - 0.008*(triceps skinfold + subscapularis skinfold) ² - 3.4. The peak Height Velocity PHV was calculated (Mirwald et al., 2002), where PHV = -9.236 + 0.0002708 (Lower limb length * Trunk length) - 0.001663 (Age * Lower limb length) + 0.007216 (Age * Trunk length) + 0.02292 (Body mass/height * 100).

A standardized warm-up protocol was implemented, consisting of slow jogging, dynamic stretching, and 20-meter runs at varying speeds to adequately prepare participants for subsequent testing. Following the warm-up, participants completed the RSA protocol, which involved seven 30-meter sprints with 20 seconds of active recovery between each repetition. HR bpm was continuously monitored using Polar M400 devices equipped with H-9 Bluetooth Smart sensors before the test began and after each sprint repetition. Additionally, LA, (mmol/L) was measured via finger stick at three specific time moments: prior to the test, after the fourth sprint, and immediately following completion of the RSA. The assessment utilized a range of specialized equipment, including Polifemo-radio version 2.0 infrared photocells for sprint timing, a SECA 213 portable stadiometer for height measurement, a SECA 874 floor scale for body mass assessment, Harpenden Calipers model SFC-1000 for skinfold thickness evaluation, a CASIO HS70 stopwatch for timekeeping, and a Lactate Scout 4Start analyzer for lactate measurements.

Variables obtained from the 7x30m-20" RSA test

The RSA mean time of all repetitions was considered the primary RSA performance variable. The best sprint was also considered, and the maximum speed attained was calculated using the formula: Max Speed (km/h) = distance / best time. Finally, theoretical fatigue was estimated using the fatigue index FI, presented below as equation 1 (Bishop et al., 2001), and percentage decrement score (Sdec%), presented as equation 2 (Spencer et al., 2005).

Equation 1.

$$\boldsymbol{FI} = 100 * \frac{(best\ sprint - worst\ sprint)}{Best\ sprint}$$

Equation 2.

$$\boldsymbol{Sdec}\,\% = 1 - \frac{(S1 + S2 + S3 + S\ Final)}{Best\ sprint * \#\ sprints} * 100$$

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Analysis

A priori sample size was calculated from G * Power software (V3.1.9.2, University of Kiel, Germany). The α and power (1-β) were defined as 0.05 and 0.80, respectively, by inference, sample size of the current study is considered satisfactory. Data analysis comprised descriptive statistics for anthropometric measurements and RSA 7x30m-20" performance across the total sample. In addition, simple correlation analyses were conducted to examine relationships between test performance, HR, LA and fatigue. Finally, comparisons between age groups (12, 13, 14, and 15 years) were performed using analysis of variance (ANOVA).

The significance level was set at 5% for inferential statistics, and correlation coefficients were interpreted as follows: likely ($r < 0.1$), small ($0.1 < r < 0.3$), moderate ($0.3 < r < 0.5$), large ($0.5 < r < 0.7$), very large ($0.7 < r < 0.9$) and near-perfect ($r > 0.9$). The statistical packages IBM SPSS version 27 (IBM Corp., Armonk, NY, USA) and GraphPad Prism version 8 (GraphPad Software, San Diego, California, USA, www.graphpad.com) were used.

Results

The anthropometric characteristics of the participants are summarized in Table 1, height and body mass increased with chronological age, while fat mass decreased. Considering the total sample, simple Pearson correlations showed that RSA performance associated with age p<0.01, height p<0.05, body mass p<0.05, and PHV p<0.01; that is, as these values increased, test performance improved.

Table 1. Characterization of participants and correlations according to the performance of the RSA 7x30m-20", heart rate, and blood lactate at the end of the test.

variable	age group	X	±	SD	correlation		
					RSA	HR post	LA post
Age (yrs)	Total	14.1	±	1.07	-0.51†	0.20	0.19
	12	12.4	±	0.27	0.66	0.18	0.30
	13	13.4	±	0.26	-0.18	-0.07	-0.59†
	14	14.5	±	0.26	-0.13	0.23	0.05
	15	15.5	±	0.62	-0.28	0.31	0.34
Height (cm)	Total	161.8	±	8.51	-0.31*	0.16	0.07
	12	148.8	±	4.40	-0.35	0.29	-0.64
	13	160.9	±	5.69	0.15	-0.11	-0.07
	14	163.4	±	7.85	0.30	0.09	-0.26
	15	167.8	±	7.56	-0.14	-0.12	0.27
Body mass (kg)	Total	50.2	±	9.42	-0.30*	0.23	0.04
	12	37.2	±	4.93	-0.21	0.78*	-0.10
	13	50.5	±	9.01	0.07	0.23	-0.27
	14	51.5	±	8.51	0.20	0.69	0.28
	15	55.1	±	7.28	-0.37	-0.04	0.18
Fat mass (%)	Total	15.2	±	4.75	0.26*	-0.11	-0.04
	12	17.5	±	6.59	0.32	-0.33	-0.14
	13	15.6	±	5.35	0.11	0.21	-0.01
	14	14.3	±	4.47	-0.25	-0.29	-0.14
	15	14.8	±	2.63	0.29	0.34	0.25
PHV (yrs)	Total	-0.37	±	1.02	-0.43†	0.23	0.12
	12	-2.00	±	0.28	0.50	0.44	0.07
	13	-0.76	±	0.60	0.13	0.11	-0.53*
	14	-0.12	±	0.66	0.21	-0.03	-0.06
	15	0.76	±	0.73	-0.21	0.11	0.22

Total= (n=60); 12= (n=7);13= (n=21);14= (n=19);15= (n=13); *= p<0.05; †= p<0.01

The associations mentioned before disappeared when the anthropometric is correlated by age group. Finally, regarding the internal load generated after completing the test, only body mass was associated with final HR in the 12-year-old group p<0.05, age with LA post-test p<0.01, and PHV with LA post-test in the 13-year-old group p<0.05.

Regarding the RSA performance, Figure 1 illustrates the values for each sprint repetition, indicating a trend of higher performance in the initial sprints, followed by a progressive decline over the course of the test. Table 2 shows that RSA was not associated with the estimated theoretical fatigue indicators (FI and Sdec%). In contrast, HR was significantly correlated with RSA mean, RSA best time, and max speed (km/h) p<0.05, whereas no significant correlations were observed for lactate. Finally, FI and Sdec% were not associated with HR and LA post-tests.

Figure 2 shows the HR before and throughout the RSA 7x30m-20" for the whole sample. HR pre: 109±16 bpm; HR 1s: 154±13 bpm; HR 2s: 169±13 bpm; HR 3s: 175±10 bpm; HR 4s: 177±10 bpm; HR 5s: 176±11 bpm; HR 6s: 180±11 bpm; HR

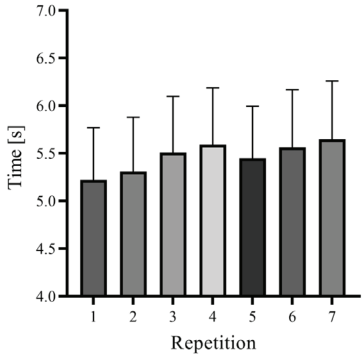

Figure 1. Performance of the RSA 7x30m-20" for each repetition expressed in RSA mean for the total sample (n=60).

Table 2. Performance of the RSA 7x30m-20", relationship with physiological indicators, and correlations between estimated theoretical fatigue and internal load of the test in the total of participants (n=60)

variable	X	±	D.E	correlation		
				RSA	HR Post	LA Post
RSA Mean (s)	5.46	±	0.54	-	-0.27*	-0.09
RSA Min (s)	5.13	±	0.51	0.95†	-0.28*	-0.13
Max. Speed (km/h)	21.23	±	2.16	-0.93†	0.28*	0.14
RSA Fatigue Index	-13.54	±	6.43	-0.07	0.01	-0.09
RSA ($S_{dec\%}$).	-6.55	±	3.60	-0.01	-0.04	-0.01

$S_{dec\%}$ = Percentage decrement score; *= p<0.05; †= p<0.01

post: 181±9 bpm. The most accelerated increase is between the pre-test and the first sprint. It gradually increases until reaching a small plateau between the 4th and 5th sprint but continues to increase until the end of the protocol. In parallel, the lactate values are represented in Figure 3, where LA increases as the test progresses: LA pre: 2.3±0.8 mmol/L; LA 4s: 8.3±2.1 mmol/L; LA post:11.2±2.1. Comparisons pre vs 4s t= 18.706; pre vs post t= 33.919 and 4s vs post t= 9.115 in all cases p<0.001.

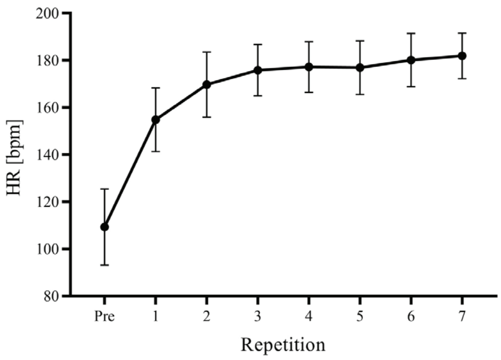

Figure 2. Heart Rate before and throughout for the RSA 7x30m-20" for the total sample (n=60).

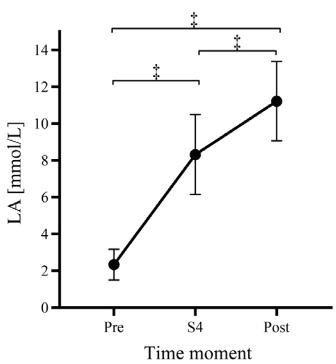

Figure 3. Comparison of blood lactate at three different times during the RSA 7x30m-20" for the total sample (n=60). ‡ = p<0.001.

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Finally, Figure 4 presents ANOVA comparisons according to age group. 4a, the RSA performance, where the 12-year-old group presented differences with the other age groups, F = 12.261, p<0.001, η^2 = 0.396; 4b, HR F = 1.135, η^2 = 0.057; 4c, LA F = 1.036, η^2 = 0.053; 4d, (Sdec%). F = 1.306, η^2 =0.065; and 4e, FI F = 0.977, η^2 =0.050.

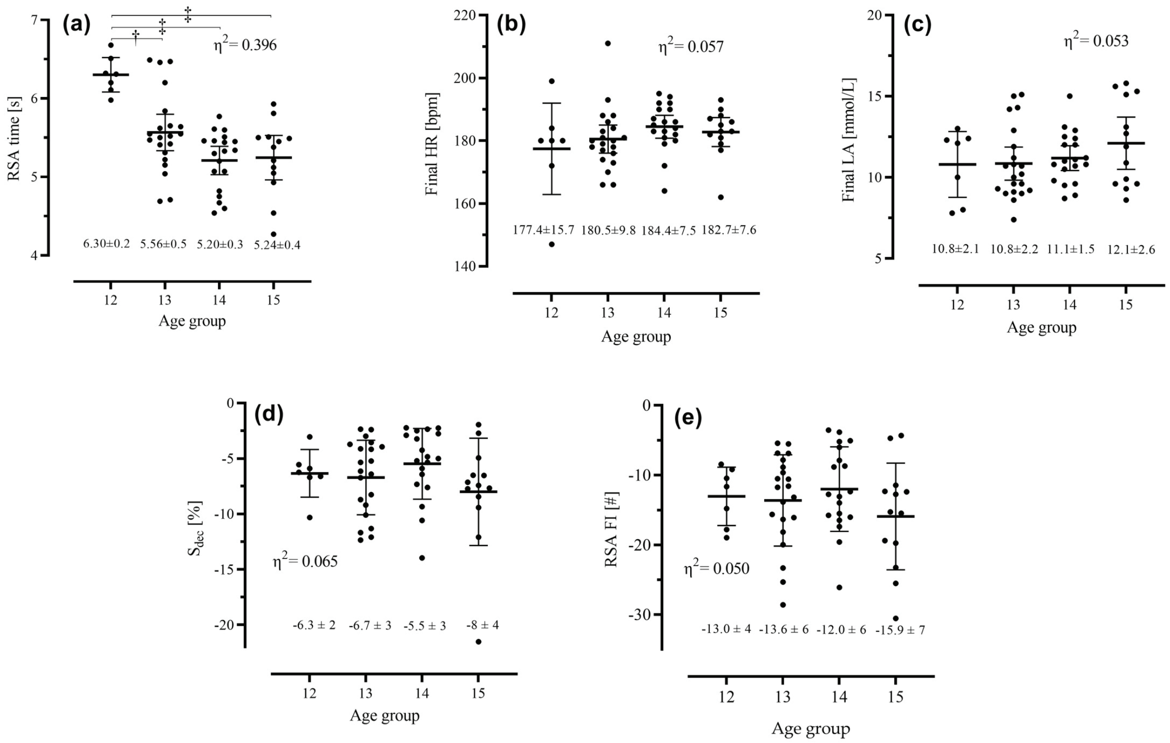

Figure 4. Comparisons by age group. 4a, RSA performance; 4b, Heart rate; 4c, Blood lactate; 4d, Fatigue index; 4e, % percentage decrement score. †= p<0.01; ‡= p<0.001.

Discussion

This study described the results of the 7x30m-20″ RSA protocol and the associated internal load in youth soccer players. First, performance tended to be better in the initial sprints and worse in the final sprints; HR and LA increased throughout the test, reaching values of 181.9 ± 9.6 ppm and 11.2 ± 2.1 mmol/L, respectively. Second, regarding the internal load, the estimated theoretical fatigue indicators were not related to HR and LA. Third, RSA was associated with anthropometric measurements; however, these findings may have been influenced by the broad age range of the participants (12-15 years). When analyzed by age groups, these associations were no longer observed, with the 12-years group demonstrating lower performance compared to de older groups. Finally, RSA performance indicators were associated with an increase in HR, but not with LA. Inter-individual variability was observed in HR, LA, and fatigue according age groups.

The results were consistent with the characteristics of the RSA test, in which performance progressively declines across repetitions as fatigue develops (Girard et al., 2017; 2011; Salazar-Martínez et al., 2025); The mean of the minimum times achieved across the total sample was 5.13 ± 0.51 s, corresponding to speeds of 21.23 ± 2.16 km/h. An age-related improvement in performance was also observed; however, the 14-year-old group demonstrated the best results, slightly outperforming the 15-year-old group. Notably, the performance of the 14-year-old group was comparable to that reported by Akdogan et al. (2019), who implemented a 7x35m-30” RSA protocol and reported a mean time of 5.35 ± 0.30s in competitive soccer players aged 14.6 ± 0.5 years. Interestingly, that study concluded that six weeks of training with small-sided games of varying formats did not results in improvements in RSA, 10m, and 30m sprint performance.

RSA performance has typically been reported in players older than 14 years; however, previous studies have employed protocols with different distances and recovery intervals, limiting direct comparisons with the present findings. For instance, Rey et al. (2019), evaluated 27 players using a 6x25m-25” RSA protocol, reporting a mean time of 4.20 ± 0.19s, concluding that training twice per week (4-6 sets of 15 repetitions over 30m) positively influenced RSA performance. Similarly, Buchheit and Méndez-Villanueva (2014), in a large sample of 270 players aged 14.5 ± 1.6 years, reported mean times of 4.71 ± 0.32s in a 10x30m-30” RSA protocol. They further suggested that 55-70% of RSA is explained by locomotor parameters of maximum aerobic speed MAS, maximum sprint speed MSS and anaerobic sprint reserve ASR, with the remaining variance likely influenced by growth, maturation and glycolytic capacity.

Consequently, evidence on RSA protocol outcomes in children under 14 years of age remains limited. This research found that the 12-year-old group exhibited lower performance compared to the other age groups, with significant differences in RSA times, possibly because adolescents tend to have more glycolytic power than children. In fact, it is important to highlight that in pre-pubertal stages, there is a predisposition for long-duration work and low-moderate intensities (Armstrong and Welsman, 2020). These findings differ from a study that included a sample of 135 Portuguese soccer players where the performance of a 7x34.2 -25” RSA with slalom was reported for 11 years old (n=40) 8.87± 0.49s, for 12 years old (n=57) 8.45± 0.45s, for 13 years old (n=83) 8.23± 0.45s, for 14 years old (n=80) 7.87± 0.33s and for 15 years old (n=66) 7.68± 0.31s, since the results they represent have an improvement of less than 5% between each age group. The study indicated that players advanced in maturation (evaluated by skeletal age) performed better than their contemporaries (Valente dos Santos et al., 2012).

Naturally peak HR values in players under 15 years of age exposed to RSA protocol loads of at least 30m are ~181 bpm (Charron et al., 2020; Gibson et al., 2017), which is consistent with the results found in this research. HR values in children and young people differ from those of adults during high-intensity exercise, mainly due to their smaller body size, incomplete maturation, and mechanical efficiencies (Mascherini et al., 2023; Dupuy et al., 2022; Armstrong and Welsman, 2020). Regarding blood lactate, values are usually around ~7.8 mmol/L in 6x30m-30” protocols in children under 15 (Charron et al., 2020; Gibson et al., 2017), increasing slightly with age. However, this work presented values higher than 10.8 mmol/L since the protocol executed had a recovery time reduced to 20 seconds, which usually affects the internal load on the RSA (Gibson et al., 2017; Padulo et al., 2015). However, lactate in children and adolescents is usually lower compared to adults in high-intensity exercises under the same conditions (Dupuy et al., 2022).

On the other hand, altitude has traditionally been used to train aerobic endurance athletes who intend to compete at lower altitudes “live low-train high” (Brocherie et al., 2017). In the case of RSA, performance is negatively affected at altitudes of 3000m since fatigue sets in more quickly (Girard et al., 2017). However, multiple sprint training at that altitude can increase the performance of a 6x40-20” RSA and decrease the estimated theoretical fatigue in soccer players of 15.3 ± 0.5 when they return to lower altitudes (Gatterer et al., 2014). It should be noted that the present research was conducted in Bogotá DC, Colombia at 2625m (a moderate altitude according to FIFA), the same place where the observed participants they live, who possibly have chronic hypoxia (Gore et al., 2008); therefore, the results found for HR and LA could be higher when comparing the same external load executed at an altitude close to sea level (Girard et al., 2017; Gore et al., 2008; Bowtell et al., 2014).

According to Bowtell et al. (2014), fatigue can worsen by up to 4.9% at altitudes of 2000–3000 m in RSA tests with 10 repetitions of 6 seconds running at maximum intensity with 30 seconds of recovery for individuals not adapted to altitude. In this study, the fatigue index and the percentage decrement score (Sdec%) increments with small proportion of total variance explained by age groups. Finally, LA values were 10.8±2.1 mmol/L for 12 years, 10.8±2.2 mmol/L for 13 years, 11.1±1.5 mmol/L for 14 years, and 12.1±2.6 mmol/L for 15 years, higher results than studies in these ages at an altitude close to sea level, which are usually ~8.0 mmol/L (Charron et al., 2020; Gibson et al., 2017).

The limitations of this study include the lack of control of rate perceived exertion (RPE) and the sample size, which limits the exploration of the pre-pubertal stage, making it necessary to extend the analysis beyond the age of 11. However, given the scarcity of studies controlling the external and internal load in RSA protocols for child and youth soccer players exposed to moderate altitude, the reason why this study is novel and of general interest to sports science. Future studies may compare internal load across different altitude levels, as well as the time required to acclimatize to varying altitudes, given that players begin competing in diverse environments from a very young age.

Conclusions

The study concludes that RSA performance in the 7×30m–20” test at an altitude of 2650m in pubertal players improves with increasing age. Test performance is similar to that of adult competitive players, with better results in the initial sprints. LA and fatigue were slightly higher in older participants and compared to other studies in this age groups; however, substantial inter-individual variability was observed in internal load across age groups.

Conflicts of Interest

The authors declare no conflict of interest.

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