Relationship between body composition and performance through a competitive season in rhythmic gymnastics

Relação entre a composição corporal e a performance ao longo de uma época competitiva em ginástica rítmica

Beatriz Alves Gonçalves

ORIENTADO POR: Dr. Tiago Ribeiro da Silva
COORIENTADO POR: Prof.ª Doutora Amanda Batista Santos

Trabalho de investigação
1.º CICLO EM CIÊNCIAS DA NUTRIÇÃO | UNIDADE CURRICULAR ESTÁGIO
FACULDADE DE CIÊNCIAS DA NUTRIÇÃO E ALIMENTAÇÃO DA UNIVERSIDADE DO PORTO

TC

PORTO, 2024

Abstract and keywords

Introduction: Understanding body composition (BC) is crucial in sports, particularly in aesthetic-focused disciplines like rhythmic gymnastics (RG).

Objectives: The current study aims were (i) characterize the BC of tier 2 and 3 rhythmic gymnasts, (ii) investigate whether there are alterations in BC throughout a competitive season of female rhythmic gymnasts, and (iii) evaluate the association of BC with RG performance.

Methodology: Thirty-seven female gymnasts (11.5 ± 2.6 years old; 13.6±2.7 training hours/week) were evaluated before the competitive season (M1) and following its conclusion (M2). Bone mineral content (BMC), lean soft tissue (LST), fat mass (FM) and FM percentage (FM%) were evaluated through dual-energy X-ray absorptiometry (DXA) and water parameters by a multispectral bioimpedance device. Additionally, anthropometric measures were also collected. Performance was assessed using regional results scores.

Results: First-division gymnasts had lower mean values of FM (-3.8±1.3 kg p=0.015) and FM% (-5.6±1.1 kg; p=0.001). Throughout the season, FM% decreased (-0.7±1.4%; p=0.007; ES [95% CI] = -0.5 [-0.8; -0.1]), while LST (0.8±1.0 kg, p<0.001; ES [95% CI] = 0.9 [0.5; 1.3]) and BMC (0.1±0.0 Kg, p<0.001; ES [95% CI] = 1.2 [0.8; 1.6]) increased. Performance was moderately negatively correlated with FM measured by an age-specific anthropometric equation (r = -0.5), DXA (r = -0.5), and the sum of 8 skinfolds (r = -0.6).

Conclusion: Significant changes in BC were observed without corresponding changes in body weight, underscoring the necessity of monitoring BC beyond body mass. Additionally, performance showed a negative correlation with all FM measurement methods employed.

Keywords: rhythmic gymnastics, body composition, performance, dual-energy X-ray absorptiometry

Resumo e Palavras-chaves

Introdução: Estudar a composição corporal (CC) é crucial, especialmente em desportos estéticos como a Ginástica Rítmica (GR).

Objetivo: Os objetivos deste estudo foram: (I) Caracterizar a CC de ginastas rítmicas de nível 2 e 3, (ii) investigar alterações na CC ao longo da época competitiva e (iii) avaliar a associação entre a CC e a performance na GR.

Metodologia: Trinta e sete ginastas (11.5 ± 2.6 anos; 13.6 ± 2.7 horas de treino/semana) foram avaliadas antes e após a época competitiva. O conteúdo mineral ósseo (CMO), massa isenta de gordura e osso (MIGO), massa gorda (MG) e percentual de gordura (MG%) foram avaliados por densitometria radiológica de dupla energia (DXA) e os parâmetros da água por bioempedância multiespectral. Adicionalmente, foram realizadas medições antropométricas. A *performance* foi obtida através dos resultados regionais.

Resultados: Ginastas de 1ª divisão apresentaram menor MG (-3.8±1.3 kg p=0.015) e MG% (-5.6 ± 1.1%; p=0,001). Ao longo da época, a MG diminuiu (-0.7±1.4%; p=0.007; ES [95% CI] = -0.5 [-0.8; -0.1]), enquanto a MIGO (0.8±1.0 kg, p<0.001; ES [95% CI] = 0.9 [0.5; 1.3]) e o CMO (0.1±0.0 Kg, p<0.001; ES [95% CI] = 1.2 [0.8; 1.6]) aumentaram. A *performance* apresentou correlação negativa moderada com a MG medida por equação antropométrica específica para idade (r = -0.5), DXA (r=-0.5) e somatório de 8 pregas (r=-0.6).

Conclusão: Mudanças significativas na CC ocorreram sem alteração na massa corporal, destacando a importância da avaliação da CC. A *performance* apresentou correlação negativa com todos os métodos utilizados para medir MG.

Palavras-Chave: ginástica Rítmica, composição corporal, performance, densitometria radiológica de dupla energia.

List of abbreviations and acronyms

BC- Body composition

BIS - Multispectral bioelectrical impedance device

BMC - Bone mineral content

BMD - Bone mineral density

CV- coefficient of variation

ES - Effect size

FCNAUP - Faculty of Nutrition and Food Sciences of the University of Porto

FFM - Fat-free mass

FM - Fat mass

FM% - Fat mass percentage

ISAK - International Society for the Advancement of Kinanthropometry

RG - Rhythmic gymnastics

TBW - Total body water

TEM - Technical error of measurement

Summary

Abstract and keywords i

Resumo e Palavras-chaves iii

List of abbreviations and acronyms v

Summary vi

Introduction 1

Objectives 3

Methodology 3

Results 7

Discussion 11

Conclusion 15

References 16

Appendix index 19

Introduction

Rhythmic Gymnastics (RG) has been an Olympic discipline for female athletes since 1984[1]. In this sport, athletes perform choreographed movements in perfect harmony with music, while demonstrating their artistry and skill using a variety of apparatus, including the rope, hoop, ball, clubs, and ribbon[2].

Gymnastics often starts at a young age[3] and peaks during adolescence[4]. It involves specialized training, extensive weekly hours, repetition of complex elements, and a diverse set of skills, prior to bone maturation[5]. The early specialization in gymnastics for children has sparked a debate about its impact on their well-being[4], with literature indicating that female gymnasts may experience delays in pubertal development and menarche onset[6]. The bone mineral accrued during childhood is closely tied to the peak bone mass achieved in adulthood; however, RG has a high potential for promoting bone density[7, 8]. According to a systematic review conducted by Jürimäe et al. (2018)[8], intensive mechanical stress resulting from gymnastic activities has been found to stimulate bone growth. It seems to help counter adverse effects such as delayed pubertal development, decreased fat mass (FM), and reduced hormone levels[8].

Examining body composition (BC) characteristics holds significant importance in sports, particularly in disciplines emphasizing aesthetics, such as RG. This data allows coaches and nutritionists to formulate tailored training and nutritional interventions by gaining insights into the physical attributes of athletes, ultimately enhancing their performance. Based on prior research, elite gymnasts are characterized by their low FM, extended limbs, and an ectomorphic

somatotype[6, 9-11]. In this context, gymnasts, coaches, and parents endeavor to maintain the gymnast morphology within the demands of this sport[12].

Several studies have established a consistent association between BC and performance outcomes in gymnastics[13-17], highlighting the significance of BC in athletic success[15-17]. However, these studies utilized two-component models for BC assessment, which rely on assumed values for fat-free mass (FFM) density (FFM_D = 1.10 g/cm^3) or hydration (Total body water (TBW)/FFM = 0.732). In contrast, dual-energy X-ray absorptiometry (DXA), recognized for its convenience and reliability[18], employs a three-component model that distinguishes lean soft tissue (LST) from bone mineral content (BMC), thereby reducing reliance on assumptions[19]. A primary advantage of DXA is its capability to measure BMC, a parameter gaining significance due to growing awareness of low energy availability and its impact on bone health[20].

Even though the existing body of literature focuses on elite RG athletes in tiers 4 (Elite/International level) and 5 (World Class), it is essential to highlight that in Portugal, the percentage of tier 2 (Trained/Developmental) and 3 (Highly Trained/National Level) RG gymnasts (98.4%) is more representative compared to tier 4 (1.6%)[21-23].

In addition, although the RG code of points doesn't specifically penalize the athletes for their BC, subjective factors such as elegance and execution can influence competition scores[2, 24]. Therefore, to gain deeper insight into performance, it's crucial to consider gymnasts at other levels of competition and other aspects, such as variations in BC and their corresponding effects.

Objectives

This study aims to (i) characterize the BC of tiers 2 and 3 rhythmic gymnasts, (ii) investigate whether there are alterations in BC throughout a competitive season of female rhythmic gymnasts, and (iii) evaluate the association of BC (body mass, height, skinfolds, girths, LST, and FM percentage (FM%)) with RG performance.

Methodology

Study design

The present study was an observational longitudinal study with two data collection moments. The first moment (M1) occurred before the beginning of the competitive period (December). The second moment (M2) occurred about a week after the conclusion of the competitive season. Some athletes ended their season in March because they did not qualify for nationals and were evaluated at that time, while the others were reevaluated in April. This study consisted of a convenience sample of rhythmic gymnasts from a Portuguese Club competing regionally and nationally. The following inclusion criteria were adopted: (1) currently participating in competitive RG, and (2) having at least one year of competitive gymnastic training. On the other hand, the exclusion criteria were: (1) experiencing an injury that prevented regular training and participation in competitions, (2) taking any medications that are known to affect body water or composition, (3) pregnancy, and (4) inability to attend the evaluation measurements.

The baseline sample consisted of 37 female gymnasts competing at a regional or national level and, according to a framework classification presented by McKay et

al. (2022)[23], it was composed of 29.7% of tier 2 (Trained/Developmental) and 70.3% of tier 3 (Highly Trained/National Level) athletes.

This study was approved (153/2023/CEFCNAUP) by the Ethics Committee of the Faculty of Nutrition and Food Sciences of the University of Porto (FCNAUP) and was conducted according to the declaration of Helsinki for Human Studies from the World Medical Association[25]. Written informed consent to participate was received from all parents or guardians of participants before testing.
All measurements were conducted at FCNAUP.

Body compositions measurements

BC assessments were conducted in the morning (between 8 am and 12 pm) after an overnight fast of at least 8 hours, avoiding moderate to vigorous exercise in the previous 24 hours.

Anthropometry

Anthropometric variables were obtained according to the International Society for the Advancement of Kinanthropometry (ISAK) protocol[26]. The anthropometric evaluation included the measurement of weight (kg), height (cm), eight skinfolds (mm) (tricipital, bicipital, subscapular, iliac crest, supraspinal, abdominal, front tight, and medial calf), and five circumferences (cm) (relaxed arm, waist, hip, tight and calf). The same anthropometrist conducted all the skinfold thickness measurements and the coefficient of variation (CV), calculated based on ten individuals with an average age of 21 years ± 3.7 (70% females), is presented in Table 1 (in appendix). The skinfolds' technical error of measurement (TEM) ranged

from 0.3 to 1.3 mm, and the CV was between 2.9% and 5.5%. TEM for circumferences ranged from 0.1 to 0.5 mm, with CV ranging between 0.4% and 0.7%.

Participants were measured for their weight and height while wearing light clothing (training clothes or hospital gown) using an electronic scale (Seca 803, Hamburg, Germany) and a stadiometer (Seca 213, Hamburg, Germany) with a resolution of 0.1 kg and 0.1 cm, respectively. Circumferences were measured with an anthropometric tape (Lufkin W606PM, Apex Tool Group, Sparks, Maryland U.S.A.) with a resolution of 0.1 cm and the skinfolds were measured using a Harpenden skinfold caliper (Baty Int., UK), with a resolution of 0.2 mm. Additionally, we employed the equations proposed by Slaughter[27] to estimate FM%.

Dual-energy X-ray absorptiometry (DXA)

DXA (Horizon Wi, Hologic, Waltham, MA, USA, Hologic APEX software version 5.6.1.3) was used to determine whole-body measures of BMC (g), bone mineral density (BMD, g/cm^2), FM (kg), FM%, and LST (kg). The same technician performed standardized scan positioning, acquisition, and analysis according to the manufacturer's guidelines. The BMC and BMD exhibited TEM and %CV of 0.03 g and 1.1% and 0.01 g/cm^2 and 1.0%, respectively. For FM and LST, the TEM remained consistent at 0.3 kg, while the CV differed with values of 1.6% and 0.7%, respectively. Finally, FM% exhibited a TEM of 0.4 % and a CV of 1.4%. These values fall below the minimum acceptable precision outlined in the official position statement by the International Society for Clinical Densitometry[28].

Bioelectrical impedance

After undergoing the DXA scan, individuals attained stable body fluid levels, prompting an immediate assessment in the same position using bioelectrical impedance. Four electrodes were positioned on the dorsal surfaces of the right foot and ankle, as well as the right wrist and hand. All the prerequisites outlined in the literature were taken into account[29]. These included observing a minimum fasting period of 8 hours and abstaining from caffeine and alcohol intake for 12 and 24 hours, respectively. All metallic items (bracelets, necklaces, earrings, etc.) were removed during the measurements. TBW, extracellular cellular water (ECW), and intracellular cellular water (ICW) were obtained by a multispectral bioelectrical impedance device (BIS) (SFB7, ImpediMed, Carlsbad, CA, USA). The TEM and CV observed for TBW, ECW, and ICW were 0.46 L and 1.38%; 0.17 L and 1.24 %; and 0.32 L and 1.66%, respectively. One gymnast's data could not be collected due to a measurement error, resulting in a final sample size of 36 participants for water compartments.

Performance

The scores at the Portuguese regional competitions determined the competitive performance in the 2023/2024 season. This is based on points obtained from four components: body difficulty, body apparatus, artistic, and execution[2]. Given that different age groups have distinct maximum score criteria, we standardized performance by calculating each gymnast's achieved score as a proportion of their possible maximum score from the best two routines in the general classification.

It is important to note that 3 gymnasts dropped out of the regional competition due to illness (n=34), and we also considered qualification for the national competition as a performance indicator.

Data Analysis

Data processing was performed using the statistical software IBM Statistical Package for Social Sciences (SPSS) 29.0 version, and the level of significance was set at $p < 0.05$ (two sided). Normality was evaluated using the Kolmogorov-Smirnov test, and descriptive statistics were performed and presented as mean±standard deviation. Independent t-tests were conducted to examine differences in anthropometric baseline characteristics between 1st and 2nd divisions, while paired t-tests were employed to evaluate BC changes over the competitive season. Pearson correlations were used to examine the association between performance and BC at M2, due to its closer temporal proximity to the regional competition. The effect size (ES) of the differences was determined using Cohen's d. The magnitude of the ES was classified according to Hopkin's scale as follows: [0; 0.2[= trivial, [0.2; 0.6[= small, [0.6; 1.2[= moderate, [1.2; 2.0[= large, ≥ 2.0 = very large[30].

Results

Our sample included 37 female athletes, 12 (32.4%) from the 1st and 25 (67.6%) from the 2nd division with an average age of 11±2.6 years, training hours of 13.6±2.7 hours/week, and an average of 5.7±2.5 years of practice. At the first measurement, 59.5% (n=22) of the participants had not yet experienced

menarche. Of those who had experienced menarche (n=15), only one took oral contraceptives (2.7%) and 8 (21.6%) reported having a regular menstrual cycle. The gymnasts were mainly in stage 1 (40.5 %) breast development and stage 1 (40.5 %) in pubic hair development. Figures 1 and 2 summarize the biological maturation and menarche participants' characteristics (in the appendix).

Baseline characteristics and BC

Table 1 presents the participants' characteristics and BC at baseline (n = 37).

Table 1 Participants' characteristics and BC at baseline.

		Whole sample (n= 37)		**1st Division** (n = 12)		**2nd Division** (n=25)	
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Age (years)		11.5	2.6	11.0	2.4	11.8	2.7
Training volume (hours/week)		13.6	2.7	16.5**	0.8	12.2	2.2
Training onset (years)		5.8	1.6	5.7	1.7	5.9	1.6
RG practice (years)		5.7	2.5	5.3	2.8	5.8	2.4
Weight (kg)		40.5	13.4	35.6	11.5	42.9	13.9
Height (cm)		147.1	13.5	143.5	13.0	148.9	13.6
BMI (kg/m^2)		18.1	3.2	16.8	2.7	18.8	3.2
BMC (kg)		1.5	0.5	1.4	0.5	1.6	0.5
Fat mass (kg)		9.8	4.1	7.5*	2.9	11.0	4.2
Fat mass (%)		24.3	4.1	21.3*	1.8	25.7	4.1
FFM (kg)		29.9	9.6	27.3	8.5	31.1	10.0
LST (kg)		28.4	9.1	25.8	8.0	29.6	9.4
Skinfolds (mm)	Triceps	10.1	3.2	7.4**	2.1	11.4	2.8
	Subscapular	6.1	2.0	5.0*	1.1	6.6	2.2
	Biceps	4.5	1.4	3.4*	0.6	5.0	1.4
	Iliacal Crest	8.0	3.4	6.3*	2.8	8.7	3.4
	Supraspinale	5.5	2.1	4.0*	1.1	6.2	2.1
	Abdominal	9.1	3.9	6.3*	2.6	10.4	3.7
	Thigh	16.1	5.5	11.4**	3.0	18.4	4.9
	Medial Calf	9.4	3.4	6.4**	1.3	10.9	3.2
	Sum of 8 skinfolds	68.7	22.1	50.3**	12.1	77.6	20.3
Body fat by Slaughter (%)		21.5	6.6	16.5**	3.8	23.9	6.3

Abbreviations: SD standard deviation. BMI body mass index. BMC bone mineral content. FFM fat-free mass. LST lean soft tissue. Comparison of means between groups was performed using the independent sample t-test. *p<0,05: significant differences **p<0,001: significant diferences.

We found that 1st division athletes had a higher weekly training volume (p<0.001), with a very large effect size (ES [95% CI] = 2.3 [1.4; 3.2]). When compared to the 2nd division, 1st division gymnasts had significantly lower mean values of FM (-3.8±1.3 Kg p=0.015), and FM% (-5.6±1.1 kg; p=0.001), with a moderate (ES [95% CI] = -0.9 [-1.6; -0.2]) and large effect size (ES [95% CI] = -1.2 [-2.0; -0.5]), respectively. All skinfold measurements displayed significant differences between 1st and 2nd divisions, with lower values observed in the highest division. It is important to note that there was a significant difference in the sum of 8 skinfolds between groups (p<0.001) with a large effect size (ES [95% CI] = -1.5 [-2.3; -0.7]).

Body composition variation

Table 2 shows BC variation from M1 to M2. During the competitive season, there was a significant mean reduction in FM% assessed through DXA (-0.7±1.4%; p=0.007; ES [95% CI] = -0.5 [-0.8; -0.1]). Furthermore, also in DXA measures, LST (0.8±1.0 kg; p<0.001; ES [95% CI] = 0.9 [0.5; 1.3]) and BMC (0.1±0.0 Kg; p<0.001; ES [95% CI] = 1.2 [0.8; 1.6]), had a significant increase. Regarding water compartments, TBW showed a significant increase (1.0 ± 0.8 kg; p<0.001) with a moderate effect size (ES [95% CI] = 1.1 [0.7; 1.6]).

Table 2 Body composition variation through the competitive season.

	Moment 1		Moment 2		Change (M2 - M1)		p - value	ES Cohen'd [95% Confidence Interval]
	Mean	SD	Mean	SD	Mean	SD		
Weight (kg)	40.5	13.4	40.9	13.1	0.4	1.3	0.075	0.3 [0.0; 0.6]
Height (cm)	147.1	13.4	148.3	13.0	1.1	1.1	<0.001	1.1 [0.6; 1.5]
BMC (kg)	1.5	0.5	1.6	0.5	0.1	0.0	<0.001	1.2 [0.8; 1.6]
Fat mass (%)	24.3	4.1	23.6	4.1	-0.7	1.4	0.007	-0.5 [-0.8; -0.1]
LST (kg)	28.4	9.1	29.2	9.0	0.8	1.0	<0.001	0.9 [0.5; 1.3]
Sum of 8 skinfolds (mm)	68.8	22.1	69.3	23.0	0.6	7.1	0.635	0.1 [-0.2; 0.4]
TBW (L)	22.3	7.1	23.2	7.0	1.0	0.8	<0.001	1.1 [0.7; 1.6]
ECW (L)	9.2	2.8	9.6	2.7	0.4	0.4	<0.001	1.1 [0.6; 1.5]
ICW (L)	13.1	4.3	13.6	4.2	0.5	0.5	<0.001	0.9 [0.5; 1.3]
Body fat by Slaughter (%)	21.5	6.6	21.3	6.3	-0.2	2.2	0.603	-0.1 [-0.4; 0.2]

Abbreviations: ES effect size. TBW Total body water. ECW extracellular water. ICW intracellular water.

When we split by division, the ES increases at 1st division in FM%, LST, and height from a small to a large one (ES [95% CI] =-1.5 [-2.3; -0.7]; (ES [95% CI] =1.4 [0.6; 2.2]) and (ES [95% CI] =1.3 [0.5; 2.1]), respectively). The percentage of changes in BC is present in Figure 3.

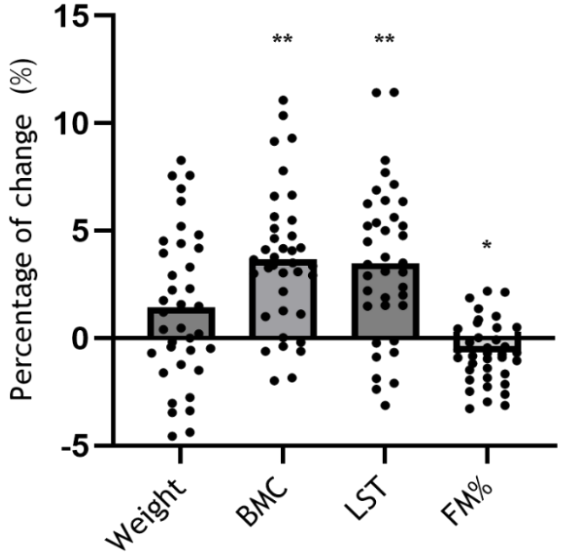


Figure 3. Mean (bars) and individual (points) percentage change in BC throughout the competitive season, measured by dual-energy x-ray absorptiometry. Comparison of means between groups was performed using the paired-sample t-test.

BMC bone mineral content. **LST** lean soft tissue. **FM%** percentage of fat mass. *Significant change ($p < 0.05$). **Significant change ($p < 0.001$).

Body composition and performance

Performance showed a significantly moderate negative correlation with all methods of measuring FM, specifically FM measured by the Slaughter equation (r = -0.5), DXA (r = -0.5), and the sum of 8 skinfolds (r = -0.6). Similar results were found for all skinfolds and girths, where higher values were correlated to worse performance results. Additionally, higher values of weight (r = -0.4) and BMI (r = -0.4) were negatively associated with performance, showing a weak correlation. The sum of 8 skinfolds explained 35% of the performance ($r^2 = 0.35$).

Regarding qualification for the national competition, the non-qualified group exhibited higher values of FM% measured through DXA (4.3 ± 1.4 kg; p=0.004), as well as FM measured by the slaughter equation (6.6 ± 2.1 kg; p=0.003) and the sum of 8 skinfolds (22.4 ± 7.8 kg; p=0.007). The first two demonstrated a large effect size ([95% CI] = 1.2 [0.4; 1.9] and [95% CI] = 1.2 [0.4; 2.0]), respectively, while the latter exhibited a moderate effect size (ES [95% CI] = 1.0 [0.3; 1.8]).

Discussion

The key findings of this study are twofold: (1) significant changes in BC occurred during the competitive season without corresponding changes in body weight, highlighting the importance of monitoring BC beyond just body mass, and (2) performance was negatively correlated with all methods of measuring FM, indicating that higher FM is associated with lower performance levels. Previous research has studied the relationship between BC and performance, but they used

two-compartment model BC methodologies. Furthermore, substantial studies have focused on the BC of rhythmic gymnasts[5, 6, 15, 31-34], but there is a gap in the literature regarding variations in BC throughout a competitive season.

Concerning BC characterization, Batista et al. (2019) examined the morphological characteristics of 164 Portuguese athletes across different levels of competition (1st division- n=72; 2nd division- n= 83; Elite- n= 9)[35]. In comparison, we observed lower values in height, weight, skinfolds, and FM% (with the latter only in the first division). The potential explanation for this finding could be attributed to the fact that their sample was relatively older (13.5±2.0 years) and commenced their training at a later age (6.9±2.4 years). As expected, in line with the current study, Batista et al. (2019)[35] demonstrated that the 1st division had lower values of FM% (18.2±4.3%) compared to the 2nd division (19.4±4.2%), as well as skinfold measurements.

As normally seen in other sports, we found a decrease in FM% (-0.7±1.4%) and an increase in LST (0.8±1.0 kg)[36]. The increase in LST was accompanied by a rise in TBW, which is expected since, at the molecular level, LST consists of water, protein, non-osseous minerals, and glycogen, with water being the predominant component[37]. It is important to point out that the mean difference of FM% between moments was within the CV (1.4%) measured through DXA. However, from the 27 gymnasts who lost FM, 12 (44.4%) lost more than 1.4 FM%.

To our knowledge, only one study[38] has investigated the changes in BC throughout a competitive season in gymnasts. Vercruyssen et al. (1998)[38] observed a decrease in FM% from pre-season to post-season (21.4±6.2% to 13.3±5.9%), using Sinning regression equation[39] in female collegiate gymnasts (not specifically RG

gymnasts), while our study, using the Slaughter equation[27], found non-significant differences (p=0.603) and minimal changes in FM% (21.5±6.6% to 21.3±6.3%) between time points. However, when analysed using DXA, the results were significant (24.3±4.1% and 23.6±4.1%). The differences in the reported values may be due to variations in the samples' mean age (20.3±1.3) or the longest (1 year) time between evaluation moments. Furthermore, differences in the utilization of regression equations[20] and the use of a two-compartment model could also contribute to the variance in the findings[20]. The limited number of sites used in some equations, coupled with the lack of validation for tracking BC changes, underscores the need to discourage this conversion of skinfolds to FM%. Instead, presenting data as a sum of the 8 skinfolds offers a more accurate and reliable assessment. This approach is increasingly advocated and used for field evaluation of adiposity in sports nutrition[20].

Athletes who qualified for the national competition exhibited significantly lower mean values of FM compared to those who did not qualify. Likewise, Donti et al. (2016)[17] found that FM% was the main morphological characteristic that differentiated qualified and non-qualifiers. One possible explanation for this phenomenon is the aesthetic aspect associated with RG, which may influence the judge's perception of the exercise[14, 40]. A study conducted in German Wheel Gymnastics, an aesthetic sport, found that FM% affects the judges' perception of the exercise ($r = 0.268$; $p<0.010$)[41] and also that higher FM or weight is associated with lower performance scores. A study by Šebić-Zuhrić et al. (2008)[32] involving 127 rhythmic gymnasts, concluded that weight and FM significantly prevent the successful learning and mastery of basic body elements. Beyond the aesthetic

explanation, FM is considered a non-functional mass, with increasing amounts of FM mechanically and metabolically hindering sports performance[36].

It is important to highlight the strengths and limitations of the present study. We believe that this study makes a strong contribution to updating the knowledge about RG gymnasts, as, as far as we know, this is the first one reporting seasonal changes in the 3-compartment BC of RG gymnasts. Furthermore, we utilized the reference method to study BMD and BMC (DXA) and we ensured meticulous adherence to all preparatory conditions for BC assessment, including the abstention from exercise preceding the evaluation, as the coaches guaranteed that gymnasts didn't train within 24 hours prior to the BC evaluation. Nevertheless, some limitations should be addressed. It is evident that BC affects performance[16, 32, 35], but this is influenced by numerous factors such as flexibility, technical skills, and the ability to deal with competition-related anxiety[5, 13, 42], which were not considered in this study. Furthermore, although the water parameters were not assessed using the deuterium dilution reference method, the method used in this study has been validated against deuterium dilution[43, 44], demonstrating its reliability. We also did not include a control group to definitively ascertain whether the observed changes were truly due to the training season or simply a result of growth and development. Molgaard et al[45] conducted a one-year longitudinal study on a healthy pediatric population aged 5 to 19 years and found a consistent increase in FM% in girls aged 10 to 15.99 years. However, we observed a decrease in FM% measured by DXA (-0.7±1.4%; p=0.007), which may indicate an effect of the competitive season. In this same one-year longitudinal study, children aged 10 to 12 years, presented a LST rate increase by approximately 4.5

kg per year. In the current study, given the 18-week gap between M1 and M2, it was anticipated that LST would increase by ≈1.56 kg. Our results showed that 21.6% of the sample demonstrated a greater increase in LST compared to the previous value, which could be attributed to the influence of the competitive season.

Conclusion

The first-division gymnasts exhibited lower levels of FM, FM% and skinfold thickness compared to their second division counterparts. Throughout the competitive season, significant changes in BC were observed without corresponding changes in body weight, underscoring the necessity of monitoring BC beyond mere body mass. Moreover, performance showed a consistent negative correlation with all FM measurement methods employed. As excessive pressure to have continuously better results and to lose weight can cause body dissatisfaction and health problems in gymnasts', coaches should be cautious when associating weight loss to improved performance, considering each gymnast's individuality. Professional monitoring and reliable body evaluation methods are essential. Furthermore, preventive measures such as official regulatory penalties for any excessive or abusive weight loss practices should be implemented.

References

1. International Olympic Committee. GYMNASTICS: History of Rhythmic Gymnastics at the Olympic Games. The Olympic Studies Centre; 2017. Disponível em: https://stillmed.olympic.org/media/Document%20Library/OlympicOrg/Factsheets-Reference-Documents/Games/OG/History-of-sports/Reference-document-Gymnastics-Rhythmic-History-at-the-OG.pdf.
2. International Gymnastics Federation. 2022-2024 code of points rythmic gymnastics. Lausanne, Switzerland: International Gymnastics Federation; 2021.
3. Silva F, Fernandes L. Desporto de crianças e jovens - um estudo sobre as idades de iniciação. Revista Portuguesa de Ciências do Desporto. 2001; 1
4. Feeley BT, Agel J, LaPrade RF. When Is It Too Early for Single Sport Specialization? The American Journal of Sports Medicine. 2016; 44(1):234-41.
5. Bobo-Arce M, Rial B. Determinants of competitive performance in rhythmic gymnastics. A review. Journal of Human Sport and Exercise. 2013; 8:S711-S27.
6. Batista A, Rui G, Avila-Carvalho L. Morphological Characteristics and Biological Maturation of Brazilian and Portuguese Gymnasts. International Journal of Morphology. 2019; 37:561-67.
7. Gruodyte-Raciene R, Erlandson MC, Jackowski SA, Baxter-Jones AD. Structural strength development at the proximal femur in 4- to 10-year-old precompetitive gymnasts: a 4-year longitudinal hip structural analysis study. J Bone Miner Res. 2013; 28(12):2592-600.
8. Jürimäe J, Gruodyte-Raciene R, Baxter-Jones ADG. Effects of Gymnastics Activities on Bone Accrual during Growth: A Systematic Review. J Sports Sci Med. 2018; 17(2):245-58.
9. Arriaza E, Rodríguez C, Carrasco C, Mardones C, Niedmann L, López A. Anthropometric Characteristics of Elite Rhythmic Gymnasts. International Journal of Morphology. 2016; 34:17-22.
10. Kritikou M, Donti O, Bogdanis G, Donti A, Theodorakou K. Correlates of artistry performance scores in preadolescent rhythmic gymnasts. Science of Gymnastics Journal. 2017; 9:165-77.
11. Irurtia Amigó A, Pons sAlA V, Busquets Faciabén A, Marina Evrard M, Carrasco Marginet M, Rodríguez Zamora L. Talla, peso, somatotipo y composición corporal en gimnastas de élite españolas (gimnasia rítmica) desde la infancia hasta la edad adulta. Apunts Educació física i esports. 2009
12. Kosmidou E, Giannitsopoulou E, Proios M. Are body esteem, eating attitudes, pressure to be thin, body mass index and training age related in rhythmic gymnastics athletes? Science of Gymnastics Journal. 2018; 10:189-201.
13. Silva MR, Paiva T. Poor precompetitive sleep habits, nutrients' deficiencies, inappropriate body composition and athletic performance in elite gymnasts. Eur J Sport Sci. 2016; 16(6):726-35.
14. Avila-Carvalho L, Klentrou P, Palomero ML, Lebre E. Body composition profile of elite group rhythmic gymnasts. Science of Gymnastics Journal. 2012; 4:21-32.
15. Miteva S, Yanev I, Kolimechkov S, Petrov L, Mladenov L, Georgieva V, et al. Nutrition and body composition of elite rhythmic gymnasts from Bulgaria. International Journal of Sports Science & Coaching. 2020; 15(1):108-16.

16. Douda HT, Toubekis AG, Avloniti AA, Tokmakidis SP. Physiological and anthropometric determinants of rhythmic gymnastics performance. Int J Sports Physiol Perform. 2008; 3(1):41-54.
17. Donti O, Bogdanis GC, Kritikou M, Donti A, Theodorakou K. The relative contribution of physical fitness to the technical execution score in youth rhythmic gymnastics. J Hum Kinet. 2016; 51:143-52.
18. Toombs RJ, Ducher G, Shepherd JA, De Souza MJ. The Impact of Recent Technological Advances on the Trueness and Precision of DXA to Assess Body Composition. Obesity. 2012; 20(1):30-39.
19. Withers RT, Laforgia J, Heymsfield SB. Critical appraisal of the estimation of body composition via two-, three-, and four-compartment models. American Journal of Human Biology. 1999; 11
20. Kasper AM, Langan-Evans C, Hudson JF, Brownlee TE, Harper LD, Naughton RJ, et al. Come Back Skinfolds, All Is Forgiven: A Narrative Review of the Efficacy of Common Body Composition Methods in Applied Sports Practice. Nutrients. 2021; 13(4)
21. Federação de Ginástica de Portugal. 5. Ginástica rítmica. In: Relatório de Atividades e Contas: 2022. 2023. p. 23-30.
22. Federação de Ginástica de Portugal. Circular Nº 0144/2023. 2023-09-19. Ginástica Rítmica| Acesso categorias Elites- Atualização.
23. McKay A, Stellingwerff T, Smith E, Martin D, Mujika I, Goosey-Tolfrey V, et al. Defining Training and Performance Caliber: A Participant Classification Framework. International Journal of Sports Physiology and Performance. 2021; 17:1-15.
24. Avila-Carvalho L, Klentrou P, Palomero M, Lebre E. Anthropometric profiles and age at menarche in elite group rhythmic gymnasts according to their chronological age. Science & Sports. 2013; 28:172–80.
25. Association WM. World Medical Association Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects. JAMA. 2013; 310(20):2191-94.
26. Esparza-ros F, Vaquero-Cristóbal R, Marfell-Jones M, Marfell-Jones M, International Society for Advancement of Kinanthropometry. International Standards for Anthropometric Assessment, 20019. International Society for the Advancement of Kinanthropometry (ISAK); 2019.
27. Slaughter MH, Lohman TG, Boileau RA, Horswill CA, Stillman RJ, Van Loan MD, et al. Skinfold equations for estimation of body fatness in children and youth. Hum Biol. 1988; 60(5):709-23.
28. Hangartner TN, Warner S, Braillon P, Jankowski L, Shepherd J. The Official Positions of the International Society for Clinical Densitometry: acquisition of dual-energy X-ray absorptiometry body composition and considerations regarding analysis and repeatability of measures. J Clin Densitom. 2013; 16(4):520-36.
29. Kyle UG, Bosaeus I, De Lorenzo AD, Deurenberg P, Elia M, Manuel Gómez J, et al. Bioelectrical impedance analysis-part II: utilization in clinical practice. Clin Nutr. 2004; 23(6):1430-53.
30. Cohen J. Statistical Power Analysis for the Behavioral Sciences. Taylor & Francis; 2013.
31. Martínez-Rodríguez A, Reche-García C, Martínez-Fernández MDC, Martínez-Sanz JM. [Assessment of nutritional-dietary status, body composition, eating

behavior, and perceived image in rhythmic gymnastics athletes]. Nutr Hosp. 2020; 37(6):1217-25.
32. Šebić L, Tabaković M, Hmjelovjec I. Predictive values of morphological characteristics in rhythmic gymnastics. Sport Scientific and Practical Aspects International Scientific Journal of Kinesiology. 2008
33. Soric M, Misigoj-Durakovic M, Pedisic Z. Dietary Intake and Body Composition of Prepubescent Female Aesthetic Athletes. International Journal of Sport Nutrition and Exercise Metabolism. 2008; 18(3):343-54.
34. Villa M, Villa-Vicente JG, Seco-Calvo J, Mielgo-Ayuso J, Collado PS. Body Composition, Dietary Intake and the Risk of Low Energy Availability in Elite-Level Competitive Rhythmic Gymnasts. Nutrients. 2021; 13(6)
35. Batista A, Rui G, Avila-Carvalho L. Morphological characteristics of Portuguese rhythmic gymnasts in diferente competition levels. Collegium antropologicum. 2019
36. Lukaski H, Raymond-Pope CJ. New Frontiers of Body Composition in Sport. Int J Sports Med. 2021; 42(7):588-601.
37. Wang ZM, Pierson RN, Jr., Heymsfield SB. The five-level model: a new approach to organizing body-composition research. Am J Clin Nutr. 1992; 56(1):19-28.
38. Vercruyssen M, Shelton L. Intraseason changes in the body composition of collegiate female gymnasts. J Sports Sci. 1988; 6(3):205-17.
39. Sinning WE. Anthropometric estimation of body density, fat, and lean body weight in women gymnasts. Med Sci Sports. 1978; 10(4):243-9.
40. Oliveira Ld, Costa VR, Antualpa KF, Nunomura M. Body and performance in rhythmic gymnastics: Science or belief? Science of Gymnastics Journal. 2021; 13(3):311-21.
41. Weber J. The relationship between the percentage of body fat and judging in german wheel gymnastics. Science of Gymnastics Journal. 2021; 13(3):425-37.
42. Hume PA, Hopkins WG, Robinson DM, Robinson SM, Hollings SC. Predictors of attainment in rhythmic sportive gymnastics. J Sports Med Phys Fitness. 1993; 33(4):367-77.
43. Moon JR, Smith AE, Tobkin SE, Lockwood CM, Kendall KL, Graef JL, et al. Total body water changes after an exercise intervention tracked using bioimpedance spectroscopy: A deuterium oxide comparison. Clinical Nutrition. 2009; 28(5):516-25.
44. Moon JR, Tobkin SE, Roberts MD, Dalbo VJ, Kerksick CM, Bemben MG, et al. Total body water estimations in healthy men and women using bioimpedance spectroscopy: a deuterium oxide comparison. Nutrition & Metabolism. 2008; 5(1):7.
45. Mølgaard C, Michaelsen KF. Changes in body composition during growth in healthy school-age children. Applied Radiation and Isotopes. 1998; 49(5):577-79.

Appendix index

Table 1. Anthropometric coefficient of variation 20

Figure 1. Participants Tanner stages 21

Figure 2. Menarche Characteristics.....22

Table 1. Anthropometric coefficient of variation

	Variables	CV%
Skinfolds	Triceps	3,32%
	Subscapular	2,85%
	Biceps	4,84%
	Iliacal Crest	5,52%
	Supraspinale	3,89%
	Abdominal	3,89%
	Front thigh	5,06%
	Medial calf	4,72%
Circunferences	Arm (relaxed)	0,44%
	Waist (minimum)	0,49%
	Gluteal (hip)	0,53%
	Thigh (mid-troch-tib. Lat)	0,67%
	Calf (maximum)	0,49%

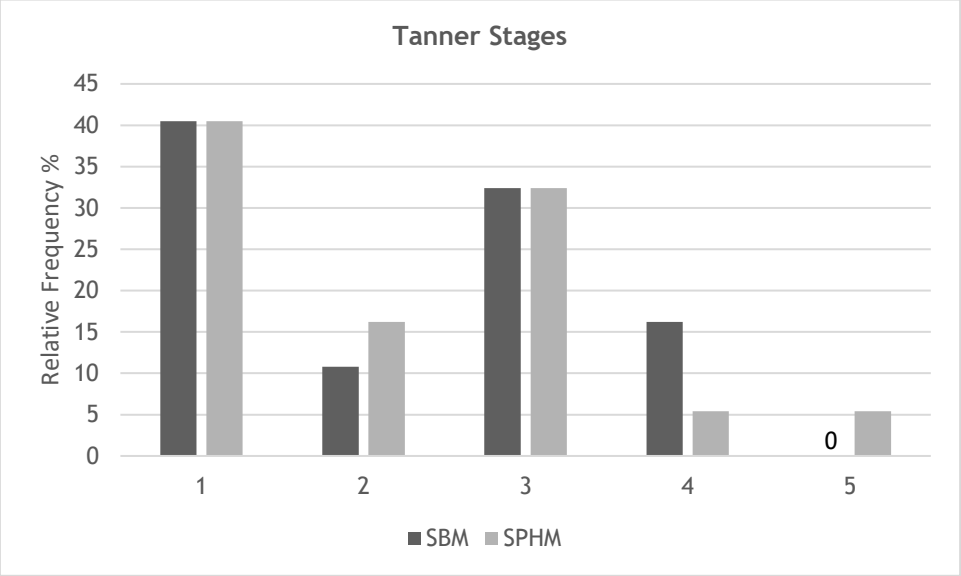


Figure 1. Participants Tanner stages

Legend: SPHM sexual pubic hair maturation. SBM sexual breast maturation.

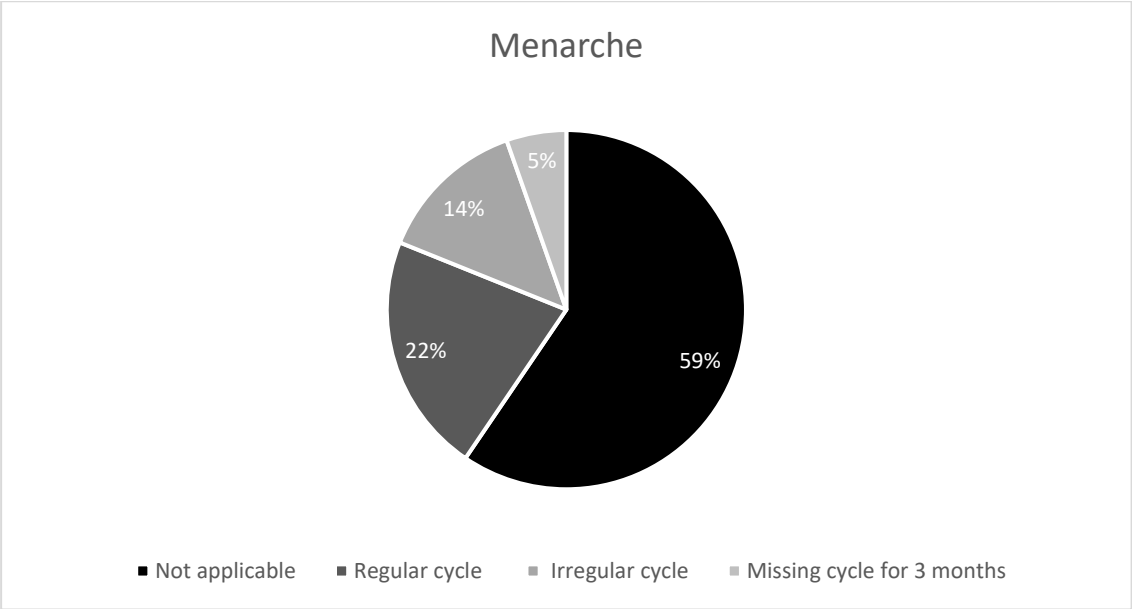


Figure 2. Menarche Characteristics

