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The Association Between Muscle Strength, Body Cell Mass, and Training Session Hours in Young Female Artistic Gymnasts: A Pilot Study

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Abstract

The identification of factors related to performance that can be improved during training is of primary interest for athletes. However, little is known about this issue among artistic gymnasts. The current pilot study aims to assess the association between training factors and anthropometric, body composition, and muscle strength (MS) variables in adolescent female artistic gymnastics. A total of 22 young female artistic gymnasts taking part in a professional team, who had a median age of 12.21 years and a median body mass index (BMI) of 18.72 kg/m^2, were categorized into a competitive-level (8.00–17.00 h [h]/week) group (n = 16) and a pre-team-level (<4 h/week) one (n = 6). The training factors considered were (i) training hours per session, (ii) training hours per week, and (iii) training years. All the participants underwent complete anthropometric measurements, including body composition assessments by means of bioelectrical impedance vector analysis (BIVA), and an objective physical activity evaluation with a portable accelerometer SenseWear Armband (SWA). MS was assessed using a handgrip dynamometer. The correlation and partial correlation were evaluated to test the associations between variables. The competitive-level group had higher fat-free mass (FFM), body cell mass (BCM), and MS compared to the pre-team group. However, after adjusting for confounders, only the number of training hours per session was associated with MS (ρ = 0.445, $p < 0.05$) and BCM (ρ = 0.475, $p < 0.05$). In conclusion MS and BCM but not FFM are correlated with the number of training hours per session. Future studies are needed to test the effects of specific programs based on this training parameter on these variables, to determine whether they can impact athletic performance in young female artistic gymnasts.

Keywords: body composition; sport performance; physical fitness; adolescent; physical activity

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1. Introduction

In any sport discipline, training physically and mentally prepares athletes to achieve optimum performance during competition [1–3]. The identification of factors that can be improved during training sessions and which can be translated into the achievement of better health and growth, injury prevention, and sport performance is of primary importance for an athlete, coach, or team in any sport [4,5]. Traditionally, attention is usually placed on the macro compartments of body composition, classically dividing body mass into two elements: fat mass (FM), which includes subcutaneous and visceral adipose tissues, and fat-free mass (FFM), represented mainly by muscle and bones [6,7]. Quantifying body composition plays an important role in monitoring athletes' performance and training regimens in almost all sport disciples [8].

Despite the fact that the quantitative body composition compartments (i.e., high FFM and low FM) are crucial and strongly related to athletic performance in general, as well as in artistic gymnasts specifically, other variables are increasingly gaining attention [9–11]. For instance, muscle strength (MS) is strongly linked to overall performance in most sport disciplines [12]. Artistic gymnastics is a demanding Olympic sport; gymnasts require high levels of MS to successfully and safely perform a dynamic and diverse set of movement skills in sequence [13]. In fact, high handgrip strength in artistic gymnastics has been shown to be crucial, as it is associated with better sport performance and a reduced risk of injuries [14,15]. In this direction, body cell mass (BCM)—which represents the metabolically active portion of FFM and indicates the cellular components of the body involved in oxygen consumption and resting energy expenditure [16]—also appears to be a highly sensitive tool for assessing nutritional status in several populations [17,18], as well as a strong predictor of muscle efficiency and performance in athletes [19]. However, there is still a lack of knowledge regarding the role of BCM in artistic gymnasts.

Based on these considerations, the aim of this pilot study is to test the feasibility and to compare two groups of artistic gymnasts, categorized into pre-team and competitive-level groups, which differed primarily in training intensity, expressed in total "hours (h)/week" and "hours/session", and to investigate potential associations between the training parameters and anthropometric, body composition, and MS variables in this population.

2. Materials and Methods

2.1. Participants and Design of the Study

A protocol including anthropometric, body composition, physical activity assessment, and MS testing was designed. It involved a group of young female artistic gymnasts from the "La Patria 1879" team (Carpi, Modena, Italy), who train at a professional level and volunteered to participate in the study.

No exclusion criteria for participation in the study were defined, except that the participants should be healthy and not affected by any chronic disease or prior injuries that represent a contraindication to practicing artistic gymnastics. After being informed about the protocol procedures, 22 young female athletes with an age range between 11 and 13 years and their parents agreed to participate during their off-season period. Six of them were categorized into the pre-team group, according to their training schedule of 2–4 h/week, while 16 were considered athletes, training for between 8 and 17 h per week. The investigation was designed, reviewed, and approved on 24 March 2025 by the Institutional Review Board of the University of Modena and Reggio Emilia (protocol no. 45558), and all the parents of the participants signed a written informed consent form (Prot. 45558, UNIMORE Ethics Committee for Research).

2.2. Training Information

The following training information was retrieved through individual interviews, and at the same time, and some socio-demographic data (i.e., age, education level, etc.) were collected:

- Training hours per session: the number of hours in each session of training, expressed in h/session;
- Training hours per week: the total number of hours of training in a week, expressed in h/week;
- Training years: the duration, for which the participant had been training, expressed in years.

2.3. Body Weight and Height

The body weight of each participant was measured to the nearest 0.1 kg using a mechanical weighing scale (SECA 861-7021099, Hamburg, Germany), and height to the nearest 0.5 cm with a stadiometer (SECA 225-1721009, Hamburg, Germany) [20]. The body mass index (BMI) was then determined according to the standard formula of body weight (kg) divided by the square of the height (m^2) [21]. Finally, the BMI standards for Italian youth proposed by Mascherini and colleagues were used to evaluate BMI status [22].

2.4. Skinfold Thickness and Circumferences

The skinfold thickness and body circumference measurements were obtained using the International Society for the Advancement of Kinanthropometry (ISAK) protocol [23], by dietitians involved in the study who previously received an advanced training by a specialized anthropometrist from the Center for the Study of Metabolism, Body Composition, and Lifestyle (MBL-center) at the University of Modena and Reggio Emilia, Italy. The skinfold thickness (ST) was measured in triplicate to the nearest 0.2 mm with skinfold calipers (HOLTAIN LTD., 98610, Crosswell, Crymych, Pembrokeshire, UK) at the biceps, triceps, subscapular, supra-iliac, and anterior and posterior thigh sites. The same trained dietitians involved in the study recorded all the ST measurements [24,25]. Moreover, mid-upper-arm, waist, hip, chest, shoulder-width, thigh, and calf circumferences were assessed with a retractable measuring tape to the nearest 0.1 cm [24,25].

2.5. Muscle Strength

MS was assessed by means of handgrip strength, according to international guidelines [26]. The handgrip strength test was performed using a calibrated Jamar® Hydraulic Hand Dynamometer (5030J1, Chicago, IL, USA). Measurements were taken after asking the participant to sit on a standard chair with her feet flat on the floor and arm at 90° to the body, to squeeze the dynamometer tightly with maximum force, and to then release it. Two measurements were made in each hand, and the maximum value (kg) was recorded [27,28].

2.6. Body Composition

A bioelectrical impedance analysis was undertaken with a phase-sensitive impedance device (BIA 101 BIVA PRO, Akern System, Firenze, Italy) in compliance with the manufacturer's guidelines [29–31]. Before the measurement was taken, participants were invited to empty their bladders; after that they were instructed to remove all objects and accessories that contained metal and rest in a supine position, isolated from the ground and electrical conductors, with their legs abducted at 45°, shoulders abducted at 30° relative to the body midline, and hands pronated [30]. After cleaning the skin with isopropyl alcohol, two adhesive electrodes (Biatrodes Akern Srl, Firenze, Italy) were applied on the surface of the right hand and two on the right foot, according to the guidelines for athletes [30,31].

All measurements were carried out in a temperature-controlled room. Resistance (Rz), reactance (Xc), and impedance (Z) were the raw measurements used by the BODYGRAM® HBO to calculate/estimate the following variables:

- Total fat mass (FM): the total fat mass expressed in kg;
- Total fat mass percentage (FM%): the total fat mass in kg out of the total body weight in kg, expressed as a percentage;
- Total fat-free mass (FFM): the total fat-free mass, expressed in kg;
- Total fat-free mass percentage (FFM%): the total fat-free mass in kg out of the total body weight in kg, expressed as a percentage;
- Phase angle (PhA°): [arctangent (Xc/R) × 180°/π], expressed in degrees (°);
- Body cell mass (BCM): the metabolically active proportion of FFM, expressed in kg.

2.7. Physical Activity Assessment

The gymnasts were fitted with a SenseWear Armband (SWA, Body Media Inc., Pittsburgh, PA, USA) in order to assess their physical activity. The SWA is known to be a valid tool for evaluating physical activity, as compared with gold-standard instruments in children, adolescents, and adults [32,33]. This device relies on a two-axis accelerometer and sensors to detect heat flux, galvanic skin response, skin temperature, and near-body ambient temperature minute by minute, and thereby automatically calculates the energy expended in physical activity based on body weight and height. The participant's handedness and smoking status (smoker or non-smoker) were also taken into account, and the participants were instructed to keep the SWA in place over the triceps muscle on the upper left arm for seven whole consecutive days, except for when they bathed or risked wetting it. At the end of the monitoring period, the data provided from at least four complete days were considered valid [34], and proprietary SWA 7.0 software was used to calculate the following four variables per day:

- Duration of moderate physical activity (MPA): the duration of physical activity equal to or greater than three metabolic equivalent tasks (METs), expressed in minutes;
- Daily steps (DS): the number of steps recorded during each 24 h period, expressed in number of steps;
- Physical activity level (PAL): the level of physical activity, expressed in METs;
- Total distance (TD): the total distance computed per day, expressed in km.

2.8. Statistical Analysis

Continuous variables were presented as medians and interquartile ranges (IQR). The normality of variables in the overall sample was tested using the Shapiro–Wilk test. For comparison between groups, a univariate analysis was performed using the non-parametric Mann–Whitney U test with exact p values, due to the small and unbalanced sample size [35,36]. Accordingly, Leven's test for homogeneity of variances was used to test the equality of variances between groups. Where the variables did not meet the equal variance assumption, Welch's test was performed for comparison instead of the Mann–Whitney test. Pearson's correlation was utilized to evaluate the correlation between training parameters and the outcomes of interest. Where normality was violated, a bias-corrected and accelerated (BCa) bootstrap with 2000 resamples [37] was applied to estimate Pearson's ρ, and its robust 95% CI significance was based on a 95% CI excluding zero. Additionally, a two-tailed permutation test with 5000 randomization [38] was used to compute a non-parametric p value; significance was based on a $p < 0.05$, which reflects the proportion of random rearrangement that yielded—under the null hypothesis—a correlation greater than or equal to the observed correlation. A significant correlation indicated by bootstrapping and a permutation test confirmed that the observed Pearson's correlation was unlikely to occur by chance. A correlation coefficient falling between 0.3 and 0.5 was considered low and negligible, 0.5–0.7 moderate, 0.7–0.9 high, and 0.9–1.0 very high [39]. To confirm the association, a partial correlation analysis was performed, correcting for variables that were significantly correlated with the outcomes of interest. All tests were considered significant at $p < 0.05$.

All statistical analyses were computed with the Statistical Package for Social Sciences (IBM SPSS version 26) and Rstudio (Posit team 2025).

3. Results

The overall study sample consisted of 22 young female artistic gymnasts with a median age of 12.21 years (interquartile range [IQR]: 11.75–12.95 years) and a median BMI of 18.72 kg/m^2 (IQR: 17.27–20.69 kg/m^2) (Table 1). Based on the BMI standards for the Italian youth sports population [22], all the participants fell within the acceptable age-specific percentile range (3rd and 85th). The values for all the circumference and ST measurements are reported in Table 1. The non-parametric Mann–Whitney U test or Welch's test indicated no statistically significant group difference with respect to age, anthropometric, and circumference parameters ($p > 0.05$).

Table 1. Anthropometric parameters among young female artistic gymnasts $^{\gamma}$ ($n = 22$).

	Total $n = 22$	Competitive Team $n = 16$	Pre-Team $n = 6$	Significance
		Median (IQR)		
Age (years)	12.21 (11.75–12.95)	12.37 (11.90–13.12)	12.04 (11.03–12.82)	0.253
Weight (kg)	43.70 (39.50–49.60)	44.90 (41.23–50.00)	41.30 (31.18–47.35)	0.225
Height	151.50 (146.08–158.55)	152.85 (148.25–158.15)	146.70 (139.45–160.28)	0.375
BMI (kg/m^2)	18.72 (17.27–20.69)	18.78 (18.50–20.71)	17.79 (16.03–20.55)	0.178
Body circumferences				
Mid-upper-arm circumference (cm)	23.00 (22.00–24.63)	23.00 (22.15–24.88)	22.20 (19.00–24.63)	0.236 ¥
Waist circumference (cm)	65.20 (61.93–69.55)	65.00 (62.25–67.85)	67.70 (56.50–73.88)	0.873 †
Hip circumference (cm)	82.25 (77.75–85.90)	82.75 (78.38–86.50)	80.50 (70.88–87.50)	0.482 ¥
Chest circumference (cm)	76.10 (70.80–78.90)	76.35 (71.00–79.30)	73.50 (66.38–80.15)	0.602 ¥
Shoulder width (cm)	42.00 (40.00–43.00)	42.25 (40.13–43.75)	40.50 (37.75–41.25)	0.054 ¥
Thigh circumference (cm)	41.05 (38.88–42.48)	41.55 (40.25–42.83)	39.50 (35.98–43.00)	0.194 ¥
Calf circumference (cm)	31.40 (29.00–32.13)	31.50 (30.25–32.38)	30.40 (27.88–32.25)	0.315 ¥
Skinfolds thickness				
Triceps skinfold (mm)	11.00 (9.00–13.25)	10.55 (9.13–12.75)	12.50 (8.50–14.75)	0.504 ¥
Biceps skinfold (mm)	5.05 (4.00–6.63)	5.00 (4.00–5.88)	6.50 (4.00–10.88)	0.235 †
Subscapular skinfold (mm)	7.00 (6.00–8.63)	7.00 (6.00–8.38)	7.25 (5.00–10.05)	1.000 †
Supra iliac ckinfold (mm)	6.00 (5.00–7.70)	6.00 (5.13–7.38)	7.00 (4.48–14.38)	0.292 †
Thigh anterior skinfold (mm)	18.50 (16.00–23.25)	18.50 (16.25–22.00)	20.50 (15.25–32.25)	0.415 †
Thigh posterior skinfold (mm)	23.00 (16.00–28.25)	23.00 (17.50–27.50)	22.00 (15.00–29.75)	0.919 †

BMI = body mass index; $^{\gamma}$ values are medians (IQR); ¥ results for Mann–Whitney test with significance considered for exact 2-sided p value; † results for Welch's unequal variance test.

With regard to composition, the median FFM was 36.05 kg (IQR: 32.90–39.70 kg) and the FFM% was 81.60% (78.45–84.73%). The median FM was 8.10 kg (IQR: 6.43–9.63 kg) with a median FM% of 18.40% (IQR: 15.28–21.55%). The median BCM was 20.15 kg (IQR: 17.23–21.93 kg) and the median PhA° was 6.30° (IQR: 5.80–6.50°) (Table 2). The non-parametric Mann–Whitney U test indicated that the competitive-level team demonstrated a significantly higher FFM (median: 37.75 kg [IQR: 33.93–40.68 kg] vs. median: 32.90 kg [IQR: 26.68–36.28 kg]) and BCM (median: 21.00 kg [IQR: 19.00–22.83 kg] vs. median: 16.95 kg [IQR: 14.53–20.18 kg]) compared to the pre-team one. The PhA°, FFM%, FM (kg), and FM% did not differ significantly between the two groups of gymnasts (Table 2).

Table 2. Body composition parameters measured by BIVA among young female artistic gymnasts $^{\gamma}$ (n = 22).

	Total n = 22	Competitive Team n = 16	Pre-Team n = 6	Significance ¥
		Median (IQR)		
FFM (kg)	36.05 (32.90–39.70)	37.75 (33.93–40.68)	32.90 (26.68–36.28)	0.039
FFM (%)	81.60 (78.45–84.73)	81.65 (80.45–84.98)	78.40 (76.03–83.33)	0.183
FM (kg)	8.10 (6.43–9.63)	8.10 (6.13–9.58)	8.20 (5.90–11.38)	0.900
FM (%)	18.40 (15.28–21.55)	18.35 (15.03–19.55)	21.60 (16.68–23.98)	0.183
BCM (kg)	20.15 (17.23–21.93)	21.00 (19.00–22.83)	16.95 (14.53–20.18)	0.016
PhA°	6.30 (5.80–6.50)	6.30 (5.85–6.50)	6.00 (5.40–6.38)	0.170

BIVA = bioelectrical impedance vector analysis; FFM = fat-free mass; FFM% = FFM percentage; FM = fat mass; FM%= FM percentage; BCM = body cell mass; PhA° = phase angle; ° = degrees; $^{\gamma}$ values are medians (IQR); ¥ results for Mann–Whitney test with significance considered for exact 2-sided p value.

For the training variables, the median number of training hours per session was 2.67 h (IQR: 1.94–3.33 h), the median number of training hours per week was 8.00 h (IQR: 4.38–17.00 h), and the median number of total training years was 4.00 years (IQR: 3.00–5.25 years) (Table 3). Regarding MS, the median was 20.50 kg (IQR: 17.00–24.00 kg) (Table 3). For armband parameters, the median PAL was 1.50 METs (IQR: 1.40–1.62), the median number of DS was 8929.33 (IQR: 6939.08–9985.25), the median DS was 8.98 km (IQR: 7.16–10.58), and the median duration of MPA in minutes per day was 107.92 (IQR: 91.46–153.04) (Table 3).

Table 3. Training and physical activity parameters and performance tests for young female artistic gymnasts (n = 22) $^{\gamma}$.

	Total n = 22	Competitive Team n = 16	Pre-Team n = 6	Significance
		Median (IQR)		
Training parameters				
Hours per session (h)	2.67 (1.94–3.33)	2.92 (2.67–3.40)	1.42 (1.00–1.81)	<0.001 ¥
Hours per week (h)	8.00 (4.38–17.00)	10.63 (8.00–17.00)	3.75 (2.00–4.13)	<0.001 †
Training years (years)	4.00 (3.00–5.25)	4.00 (4.00–6.00)	3.00 (1.75–4.25)	0.058 ¥
MS in right hand (kg)	20.50 (17.00–24.00)	23.50 (18.50–25.50)	15.50 (11.50–19.75)	0.011 ¥
MS in left hand (kg)	20.00 (15.50–23.25)	21.00 (16.75–24.75)	13.00 (10.00–20.50)	0.025 ¥
MS (kg)	20.25 (16.13–23.63)	22.25 (17.63–25.13)	14.25 (10.75–20.63)	0.013 ¥
SenseWear Armband variables				
PAL (METs)	1.50 (1.40–1.62)	1.55 (1.49–1.64)	1.32 (1.28–1.39)	<0.001 ¥
DS (steps/day)	8929.33 (6939.08–9985.25)	9309.58 (8393.04–10,029.75)	6376.33 (4929.79–8215.83)	0.027 ¥
TD (km)	8.98 (7.16–10.58)	9.11 (8.44–10.77)	6.98 (4.37–8.53)	0.018 ¥
MPA (minutes)	107.92 (91.46–153.04)	141.58 (105.04–158.79)	79.08 (51.83–100.13)	<0.001 ¥

MS = muscle strength; PAL = physical activity levels; DS = numbers of step; TD = total distance; MPA = duration of moderate physical activity; $^{\gamma}$ Values are medians (IQR) for continuous variables; ¥ Results for Mann-Whitney test with significance considered for exact 2 sided p value, † Results for Welch's unequal variance test.

Regarding training parameters and performance tests, a comparison between the groups using the Mann–Whitney U test or Welch's test indicated that median training hours per session were higher among the competitive team group (median: 2.92 h/session [IQR: 2.67–3.40]) compared to the pre-team group (median: 1.42 h/session [IQR: 1.00–1.81]). A similar pattern was observed for hours per week (median: 10.63 h/week [IQR: 8.00–17.00] vs. median: 3.75 h/week [IQR: 2.00–4.13]) but not for the training years (median: 4.00 years [IQR: 4.00–6.00] vs. median 3.00 years [IQR: 1.75–4.25]; $p > 0.05$). The median MS was also significantly greater among competitive team members (median: 22.25 kg [IQR: 17.63–25.13 kg]) than pre-team members (median: 14.25 kg [IQR: 10.75–20.63 kg]). The objective assessment of physical activity reflected the higher training levels, where the competitive team had a higher median PAL (1.55 METs [IQR: 1.49–1.64]) compared to the pre-team group (median: 1.32 METs [IQR: 1.28–1.39]). This was also reflected in the total number of steps (median: 9309.58 steps [IQR: 8393.04–10,029.75 steps] vs. median: 6376.33 steps [IQR: 4929.79–8215.83 steps]) and total distance (median: 9.11 km [IQR: 8.44–10.77 km] vs. median: 6.98 km [IQR: 4.37–8.53 km]). The duration of MPA was also higher among the competitive team participants (median: 141.58 min [IQR: 105.04–158.79 min] vs. median: 79.08 min [51.83–100.13 min]) (Table 3).

Correlation analysis showed a significant correlation between hours per session and BCM ($\rho = 0.467$, $p < 0.05$) and MS ($\rho = 0.522$, $p < 0.05$), but not FFM ($\rho = 0.238$, $p > 0.05$) or BMI ($\rho = 0.191$, $p > 0.05$) (Table 4). Given the potentially high multicollinearity, FFM was not included simultaneously with these variables in the same partial correlation analysis. Partial correlation analysis adjusting for years of training and BMI confirmed the association, with hours per session being the only variable correlated with BCM ($\rho = 0.475$, $p < 0.05$) and MS ($\rho = 0.445$, $p < 0.05$) (Table 4).

Table 4. Correlation between training parameters and BCM and MS among young female artistic gymnasts (n = 22).

	Training Parameters								
	Training Hours per Week			**Training Hours per Session**			**Training Years**		
	ρ_p (95%CI)	**ρ_b (95%CI)**	**Permuted p**	**ρ_p (95%CI)**	**ρ_b (95%CI)**	**Permuted p**	**ρ_p (95%CI)**	**ρ_b (95%CI)**	**Permuted p**
Training hours per week	1.00	1.00	--	0.893 ** (0.797,0.955)	0.896 (0.837,0.934)	0	0.672 ** (0.349,0.852)	0.674 (0.382,0.821)	0.001
Training hours per session	0.893 ** (0.797,0.955)	0.896 (0.837,0.934)	0	1.00	1.00	--	0.620 ** (0.268,0.826)	0.622 (0.295,0.829)	0.002
Training years	0.672 ** (0.349,0.852)	0.674 (0.382,0.821)	0.001	0.620 ** (0.268,0.826)	0.622 (0.295,0.829)	0.002	1.00	1.00	--
BCM (kg)	0.339 (−0.096,0.665)	0.326 (−0.06,0.628)	0.118	0.467 * (0.057,0.743)	0.450 (0.028,0.753)	0.032	0.257 (−0.185,0.612)	0.246(−0.055,0.63)	0.244
MS (kg)	0.309 (−0.129,0.647)	0.308 (−0.097,0.592)	0.166	0.522 * (0.128,0.773)	0.510 (0.122,0.735)	0.011	0.283 (−0.158,0.629)	0.283 (−0.073,0.602)	0.201
FFM (kg)	0.238 (−0.204,0.600)	0.226 (−0.174,0.551)	0.287	0.414 (−0.009,0.711)	0.396 (−0.07,0.697)	0.056	0.218 (−0.225,0.586)	0.215 (−0.063,0.544)	0.326
BMI (kg/m^2)	0.191 (−0.250,0.567)	0.184 (−0.240,0.566)	0.387	0.248 (−0.194,0.606)	0.240 (−0.204,0.632)	0.273	0.192 (−0.250,0.568)	0.181 (−0.152,0.549)	0.386

	BCM (kg)		MS (kg)	
	Pearson's correlation	Partial correlation [¥]	Pearson's correlation	Partial correlation [£]
Training hours per week	0.339 (−0.096,0.665)	--	0.309 (−0.129,0.647)	--
Training hours per session	0.467 * (0.057,0.743)	0.475 * (0.041,0.758)	0.522 * (0.128,0.773)	0.445 ** (0.003,0.741)
Training years	0.257 (−0.185,0.612)	--	0.283 (−0.158,0.629)	--
BCM (kg)	1.00	--	0.835 ** (0.638,0.929)	--
MS (kg)	0.835 ** (0.638,0.929)	--	1.00	--
FFM (kg)	0.969 ** (0.925,0.987)	0.908 ** (0.778,0.963)	0.816 ** (0.602,0.921)	0.748 ** (0.457,0.894)
BMI (kg/m^2)	0.826 ** (0.620,0.925)	--	0.557 ** (0.177,0.793)	--

BCM = body cell mass; MS = muscle strength; FFM = fat-free mass; ρ_p (95%CI) = Pearson's correlation (95%CI); ρ_b (95%CI): bootstrap correlation (95%CI). BCM = body cell mass; MS = muscle strength; FFM = fat-free mass; BMI = body mass index. * Correlation is significant at $p < 0.05$; ** Correlation is significant at $p < 0.01$. [¥] Partial correlation was conducted for variables with significant correlation with training hours per session and adjusted for training years and BMI. [£] Partial correlation was conducted for variables with significant correlation with training hours per session and adjusted for training years and BMI.

4. Discussion

This pilot study aimed to provide benchmark data on the associations between anthropometric, body composition, and MS variables and training parameters in young female artistic gymnasts. The analysis revealed three main findings.

4.1. Findings and Concordance with Previous Studies

Our first finding is that the subgroup of female artistic gymnasts involved at a competitive level had greater MS compared to the pre-team subgroup, which notably had lower weekly training hours. Moreover, we found a significant positive association between hours per session and MS. This is of particular interest, since MS is known to be associated with improved athletic performance and serves as a protective factor against injuries in athletes in general, as well as in artistic gymnasts in particular [12–15]. Secondly, and consistent with the first finding, BCM, which is the metabolically active portion of FFM [16], was higher in the competitive subgroup of artistic gymnasts compared to the pre-team subgroup.

These findings are in line with the previous literature, including a study by Martins et al., which reported higher BCM levels in athletes (in both team and individual sports) compared to non-athletes [40]. Another investigation conducted by Andreoli et al. revealed that BCM is higher among trained athletes compared to less trained ones (soccer, judo, and water polo) [41]. Moreover, we found that BCM was strongly associated with hours per session, whereas no such association was identified when considering FFM. This is of relevant interest, since the previous literature showed that BCM is a predictive index of better athletic performance in male recreational long-distance runners [19].

In another investigation conducted by Dey et al. on young male athletes practicing various sports disciplines (i.e., football, gymnastics, hockey, and table tennis), BCM was confirmed to be a strong predictor of athletic performance as well [42]. Finally, Köhler et al. noted that BCM is strongly associated with cardiopulmonary fitness in the general population [43]. All in all, since higher BCM is linked with better sport performance and physical fitness, and given that in this study BCM—but not FFM—was correlated with training, we may speculate that BCM should be prioritized over FFM in future research. This is especially relevant if it is proven that BCM can be improved through personalized training programs, and such improvement leads to better performances in artistic gymnastics, as well as other sport disciplines. However, these hypotheses require confirmation through longitudinal evaluations.

4.2. Study Strengths and Limitations

Our study has several strengths; first, to the best of our knowledge, it is one of the very few to investigate the association between specific training factors and several anthropometric, body composition, and MS variables in competitive-level female artistic gymnasts in Italy. Second, body composition was measured using BIVA, which is known to exhibit a high level of precision in athletes [44]. Third, to evaluate MS, we relied on the Jamar® Hydraulic Hand Dynamometer (Jamar® Hydraulic), which is currently considered the gold-standard instrument [28]. Fourth, we performed an objective assessment of the physical activity patterns of our athletes during their routine daily life activities and during training hours with the SWA, which is considered a pioneering method of objectively assessing physical activity in children, adolescents, and adults [32,33,45].

However, our investigation also had some limitations. First and foremost, these include the small sample size and the pilot nature of our investigation. However, this limitation is common in research involving athletes, as it is extremely challenging to recruit a large sample in this and in other sport disciplines [46]. Secondly, the inclusion of only adolescent females practicing a specific type of sport limits the external validity of our findings, as they cannot be generalized and extended to males in the same sport or to athletes in other sports disciplines. Thirdly, the cross-sectional design of this study should be considered another limitation [47], since the association found between variables in this type of design cannot provide any information about the cause–effect relationship and does not allow for the detection of potential changes of these variables over time in this population under training. Such insights require a longitudinal interventional assessment [48]. Finally, although we did measure a wide range of variables, we cannot rule out the existence of other factors, such as oral contraceptives and menstrual cycle status, which we did not assess but may affect physical performance and body composition.

4.3. Potential Implications and New Directions for Future Research

Our findings have practical implications for the sporting environment, particularly in disciplines such as artistic gymnastics. Since MS and BCM were found to be associated with training hours per session—and given their known relationship with improved sport performance—these parameters should be considered key targets as the subject of monitoring to detect their improvements in specific and personalized training programs implemented by athletes, coaches, and teams. However, before drawing any practical conclusions, it is necessary to set out new directions for future research.

First, our findings revealed an association between training hours per session and both MS and BCM in a small sample pilot study; therefore, our findings need to be replicated in larger-sampled studies. Furthermore, since our investigation is conducted under cross-sectional circumstances without implying any causal relationship—that is, we cannot conclude that increased training necessarily leads to improvements in MS or BCM—longitudinal assessments should be conducted in order to demonstrate the effect of the training on MS and BCM. In addition, even if such a causal link exists, future investigations should test whether improvements in MS and BCM actually lead to enhanced sport performance. If all these hypotheses are confirmed in our specific population, further studies may eventually assess these findings in athletes of both genders, across different age groups, ethnicities, and sport disciplines.

5. Conclusions

Our findings highlight a meaningful association between training hours per session and key parameters such as MS and BCM, suggesting that structured training may play a critical role in optimizing these variables; however, a cause–effect relationship between them still needs to be demonstrated in future studies. This will open up promising avenues for leveraging targeted training interventions to enhance athletic performance through improvements in MS and BCM. The results of the present study—if replicated and causality is confirmed—may be useful for coaches to formulate specific and personalized training programs for their athletes to enhance MS and BCM, which can potentially improve their sport performance during competitions.

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