Physiological and Anthropometric Determinants of Rhythmic Gymnastics Performance

Helen T. Douda, Argyris G. Toubekis, Alexandra A. Avloniti, and Savvas P. Tokmakidis

Purpose: To identify the physiological and anthropometric predictors of rhythmic gymnastics performance, which was defined from the total ranking score of each athlete in a national competition. Methods: Thirty-four rhythmic gymnasts were divided into 2 groups, elite (n = 15) and nonelite (n = 19), and they underwent a battery of anthropometric, physical fitness, and physiological measurements. The principal-components analysis extracted 6 components: anthropometric, flexibility, explosive strength, aerobic capacity, body dimensions, and anaerobic metabolism. These were used in a simultaneous multiple-regression procedure to determine which best explain the variance in rhythmic gymnastics performance. Results: Based on the principal-component analysis, the anthropometric component explained 45% of the total variance, flexibility 12.1%, explosive strength 9.2%, aerobic capacity 7.4%, body dimensions 6.8%, and anaerobic metabolism 4.6%. Components of anthropometric (r = .50) and aerobic capacity (r = .49) were significantly correlated with performance (P < .01). When the multiple-regression model—\( y = 10.708 + (0.0005121 \times \text{VO}_2\text{max}) + (0.157 \times \text{arm span}) + (0.814 \times \text{midthigh circumference}) - (0.293 \times \text{body mass}) \)—was applied to elite gymnasts, 92.5% of the variation was explained by \( \text{VO}_2\text{max} \) (58.9%), arm span (12%), midthigh circumference (13.1%), and body mass (8.5%). Conclusion: Selected anthropometric characteristics, aerobic power, flexibility, and explosive strength are important determinants of successful performance. These findings might have practical implications for both training and talent identification in rhythmic gymnastics.

Keywords: kinaanthropometry, \( \text{VO}_2\text{max} \), ranking score, rhythmic gymnasts

Numerous studies have focused on morphological and physiological characteristics for successful performance\(^1-4\) and talent detection\(^5,6\) in various sports. Blanksby et al\(^7\) mentioned that the success of any talent identification and development program depends on a clear understanding of the specific performance requirements in the sport. Information on these requirements, based on a variety of

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morphological, physiological, and physical fitness measurements, is useful in any sport, including rhythmic gymnastics, a highly specialized discipline that involves the use of 5 hand apparatuses (hoop, rope, ball, clubs, and ribbon).

Elite rhythmic gymnastics athletes should have an appropriate body physique, maintain low body fat, and have specific physical abilities (ie, flexibility, explosive strength, coordination) to achieve a successful performance. Furthermore, successful performance in rhythmic gymnastics requires years of practice and training that starts at the early age of 6 years and continues until adolescence. Therefore, athletes reach a high competitive level and train intensively, stressing their cardiovascular and musculoskeletal systems during the developmental period. On the other hand, during this period growth involves changes in body size, as well as in other physiological characteristics. Apart from the interaction or the combination of natural development and the highly specialized intense training, knowledge on distinctive morphological and physiological characteristics of young high-level rhythmic gymnastics athletes would be very instructive and helpful.

A number of studies have been published on various aspects of rhythmic gymnastics, but only 2 have examined anthropometric, physical fitness, and physiological factors as predictors of attainment in rhythmic gymnastics athletes, and no agreement was found between them. Indeed, one study reported no significant relationship between performance and anthropometric measurements, aerobic power, anaerobic power, and flexibility, whereas the other found low but significant correlations between performance and physical attributes such as anthropometric measurements, explosive strength, and flexibility and outlined the importance of aerobic power.

Additional studies are needed to resolve these uncertainties. It is evident that using analytical statistical methods with a large number of measurements on morphological, physiological, and physical fitness determinants related to performance is helpful. Knowledge of the these relations might allow coaches to concentrate more on training components that affect performance and provide the appropriate criteria for better talent identification. The purpose of our study was to determine which anthropometric, physical, and physiological components among a large number of variables best explain the variability in rhythmic gymnastics performance.

**Methods**

**Subjects**

Thirty-four female rhythmic sports gymnasts (n = 34), mean age 13.41 ± 1.62 years, height 152.05 ± 8.38 cm, body mass 37.14 ± 5.74 kg, and body fat 14.01% ± 1.05%, participated in the study. The athletes were divided into 2 ability groups (elite, n = 15, and nonelite, n = 19) according to their competitive level (international and national) and their total performance-ranking scores in the national competitions. The individual total performance-ranking score was obtained by adding the composition (artistic and difficulties values) and execution scores in 4 apparatuses (ball, rope, hoop, and ribbon) according to the international rhythmic gymnastics code of points. The elite athletes were members of national teams in Greece and Cyprus, ranked at the top (first through sixth position) in national competitions, and had been training for 6.8 ± 1.8 years about 24 h/wk; nonelite gymnasts were
members of local rhythmic gymnastics teams, ranked below the sixth position in
national competitions, and had been training for 6.1 ± 1.7 years about 18 h/wk.

Procedure

All subjects were informed in detail about the experimental procedures and
signed an informed-consent statement. The ethics committee of Democritus
University approved the study. Subjects completed testing over 3 visits within
a period of 2 weeks. During the first visit, height, body mass, arm span, sitting
height, skinfold thicknesses, circumferences, and diameters were measured. All
anthropometric measurements were taken by the same trained anthropometrist
(main author). Intraclass correlation coefficients (ICCs) were used to measure
reliability based on ANOVA tables. In addition, to obtain the intratester technical
error of measurements (TEM), which is an accuracy index and represents the
measurements’ quality, the same anthropometrist measured 15 volunteer nonelite
female gymnasts on 2 different days, always in the morning, with a time inter-
val of 3 days. Reliability data indicate acceptable variability in the accuracy of
measurements (eg, for calf skinfold measurement, the ICC is $R = .99$ and TEM
$= 1.9\%$). The TEM values were calculated according to Pederson and Gore.21
The difference between the first and the second measurements was determined
for each anthropometrical point for all volunteers. The deviations obtained were
raised to the second power. Then, the results were summed ($\sum d^2$) and applied to
the equation of the absolute TEM.

$$\text{Absolute TEM} = \left(\text{the square root of } \sum d_i^2\right)/2n$$

where $\sum d^2 = \text{sum of deviations raised to the second power, } n = \text{number of volunteer}
\text{measured, and } i = \text{the number of deviations.}$

The absolute TEM was transformed into relative TEM to obtain the error
expressed as percentage corresponding to the total average of the variable to be
analyzed. In addition, we obtained the variable average value (VAV) for the first
and second days of the same volunteer. The relative TEM was calculated accord-
ing to the formula

$$\text{Relative TEM} = \text{TEM} \times \text{VAV}/100$$

where TEM = absolute technical error of measurement and VAV = variable aver-
age value.

Physical fitness attributes (hip and shoulder flexibility, leg lift forward and
sideward, 30-m sprint test, and explosive strength) were measured during the second
visit, and physiological measurements ($\text{VO}_2\text{max}$, heart rate, lactate concentration)
were obtained during the third.

Measurements

**Anthropometrics and Body Composition.** Height, body mass, arm span, skin-
fold thickness over the triceps and calf regions, 14 circumferences (shoulder, chest,
waist, abdominal, buttocks, proximal thigh, midthigh, distal thigh, calf, ankle, arm,
forearm, and wrist),22 and 8 diameters (biacromial, chest, biiliac, bitrochanteric,
knee, ankle, elbow, and wrist)23 were measured.
Standing height was measured without shoes to the nearest 1.0 cm, using a stadiometer (model 220, Seca, Hamburg, Germany). Body mass was measured to the nearest 0.1 kg using an electronic digital scale (model 770, Seca), with the subjects wearing only training shorts. Arm span was measured with the back against the wall, the arms outstretched laterally at the level of the shoulders, and the palms facing forward. Total distance from the tip of one middle finger to the tip of the other middle finger in centimeters was recorded. The sitting and standing height ratio was obtained according to the formula\(^24\) sitting height (cm) \(\times\) \(100/\)height (cm).

Skinfold thickness was measured twice with a Harpenden caliper (British Indicators Ltd) at 2 sites (triceps and calf). When a difference between the 2 trials was more than 10\%, a third measurement was taken. The mean of all the measures was used as the measurement for the particular skinfold. Body fat and lean body mass were estimated as described by Slaughter et al.\(^25\)

**Physical Fitness Tests.** Specific measurements were used to evaluate the physical characteristics of the extreme ranges of movement displayed by gymnasts during the execution of different routines. The measurements included a 30-m sprint test (seconds), sit-ups (seconds), standing long jump (cm), vertical jump (cm), a sit-and-reach test (cm), shoulder flexibility with a yardstick (cm), side splits with right and left leg forward (cm), and leg-lift tests forward (battement devant) and sideward (battement à la seconde) with the right and left legs (°).

All subjects performed the running test as fast as they could from a distance of 30 m behind the starting line using electronic timing photocells. Speed was measured to the nearest 0.01 second, with the fastest value obtained from 2 trials used as the speed score.

The sit-ups test was performed with leg lifts in 90° from the ground as fast as possible (30 repetitions). Time was recorded using a handheld stopwatch to the nearest 0.01 second.

Jumping ability and explosive strength were evaluated using standing long jump and vertical jump. For the standing long jump, the subjects stood with their feet slightly apart behind the takeoff line. Hips, knees, and ankles were slightly bent, and the subjects jumped as far as possible without hand swings. The distance from the takeoff line to the spot where the heels touch was measured to the nearest 0.1 cm. The highest score recorded over 2 trials was taken as the measure of explosive strength.

The vertical jump was measured using a jump meter (Jump MD, TKK 5106, Takei, Tokyo, Japan). The subject stood in the center of the test mat. The display unit was attached around the subject’s waist with the cable wound tight in a vertical position. The subject performed a counter-movement jump as high as possible, without a free arm movement, and landed with 2 feet on the mat. Three measurements were taken, and the highest score was recorded to the nearest 0.1 cm.

Before the assessment of flexibility, each subject performed a 5-minute warm-up consisting of a series of supervised stretching exercises. Flexibility was assessed using the sit-and-reach test, which involves sitting on the floor with legs out straight ahead. Feet (shoes off) were placed flat against the box (Bodycare Products, Southam, Warwickshire, UK). The tester held both knees flat against the floor. The athlete leaned forward slowly as far as possible and held the stretch for 2 seconds. The highest score was recorded over 2 trials to the nearest 0.1 cm.
During the shoulder-flexibility test, subjects held a numbering stick in front of the body with both hands apart and palms facing downward. They lifted the stick over the head and behind the back with the elbows fully extended, maintaining the handgrip on the stick. The subjects repeated the test, moving hands closer together each time until they could not complete the movement. The recorded score was the measure with the minimum distance between hands to the nearest 0.1 cm.

To determine the degree of flexibility in the hip, the gymnast sat sideways in a split position with 1 leg raised as high as possible off the floor. The tester measured the distance of the middle of the inferior side of the lateral malleolus from the floor with a yardstick to the nearest 0.1 cm. To evaluate functional flexibility, the athlete raised her right or left leg actively without assistance while performing an extension to the front (battement développé devant) or sideways (battement développé à la seconde). The landmarks on which the goniometer was placed were the tip of the fibular head at the lateral side of the lower leg and the middle of the inferior side of the lateral malleolus. The highest score was recorded over 2 repetitions to the nearest 1°. These measures were made on both legs (right and left).

**Aerobic Power.** After a 5-minute warm-up, VO\textsubscript{2max} was determined in the laboratory using a continuous incremental exercise protocol on a cycle ergometer (Monark, 818). Seat height was adjusted so the subject’s legs were at near full extension during each pedal revolution, and toe clips held the gymnast’s feet in place for optimal performance. Subjects were instructed to maintain a pedaling cadence of 60 rpm with a metronome.

The exercise test began with an initial load of 45 W, and the power output increased by 15 W every 2 minutes until voluntary exhaustion or the point at which the subject could no longer maintain the prescribed pedal rate. Heat rate was continuously monitored with an electrocardiograph during exercise, and blood lactate was measured 3 minutes after the maximal exercise test. During the exercise test, cardiorespiratory and metabolic variables including oxygen consumption (VO\textsubscript{2max}), carbon dioxide production (VCO\textsubscript{2}), ventilation, and respiratory-exchange ratio (RER) were measured using an automatic gas analyzer (Oxycon, Champion, Minjharht, the Netherlands). VO\textsubscript{2} and VCO\textsubscript{2} data were averaged during the final 20 seconds of each stage. The VO\textsubscript{2max} test was successfully completed when the criteria of both RER ≥1 and maximal heart rate ≥95% of age-predicted maximum were achieved.\textsuperscript{26}

**Statistical Analysis**

Descriptive statistics (means, standard deviations, range) were calculated for all variables. To quantify the dimensions supposed to underlie performance on a variety of tasks and reduce the initial set of variables, a principal-components analysis (PCA) was applied. This procedure was performed on 40 variables for the total sample of 34 rhythmic gymnasts. The coefficient display format was suppressed with absolute values less than the specified value (.50). After the omission of 13 variables according to the loading, PCA was rerun with 27 variables. Despite the difficulties in recruiting more rhythmic gymnastics athletes, the PCA procedure was found to be appropriate. In fact, the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy was equal to .562, and the Bartlett test of sphericity was significant (\(P < .001\)).
In addition, a multiple-regression procedure was used to determine the amount of variance in performance-ranking scores using the components derived from PCA. Multiple-regression models were also applied, using selected variables to determine the amount of variance in performance-ranking scores in each group separately (elite and nonelite). Pearson correlations were used to determine the relationship among the 6 components and the competitive-performance scores. Furthermore, the differences between elite and nonelite athletes were determined using \( t \) tests. An \( \alpha \) level less than .05 was used as a criterion for significance.

**Results**

The results of the independent \( t \) tests of the anthropometric characteristics, physical fitness measurements, and physiological responses during the VO\(_2\)max test between elite and nonelite rhythmic gymnastics athletes are presented in Tables 1 and 2. The analysis of data indicated that both groups had similar values in most of the variables. Moreover, elite athletes had higher values in VO\(_2\)max \( (t = 7.78, \text{df} = 32, P < .001) \), heart-rate response \( (t = .44, \text{df} = 32, P < .05) \), side split with right leg forward \( (t = 2.18, \text{df} = 32, P < .05) \), and right leg lift sideward \( (t = 2.30, \text{df} = 32, P < .05) \).

Correlation coefficients between variables and performance scores of elite \((n = 15)\) and nonelite gymnasts \((n = 19)\) and the total sample \((N = 34)\) are also presented in Tables 1 and 2. The highest correlation in the total sample was found in exercise time during the maximal test \( (r = .74) \), oxygen pulse \( (r = .73) \), and VO\(_2\)max \( (r = .72) \). Figure 1 shows the correlation coefficients for VO\(_2\)max in the total sample and both elite and nonelite athletes. In addition, most anthropometric variables were significantly related to performance in both groups separately, although correlation coefficients were higher in elite athletes (Table 1).

From the PCA analysis, 6 components were extracted and labeled in the following order: (1) anthropometric characteristics, (2) flexibility, (3) explosive strength, (4) aerobic capacity, (5) body dimensions, and (6) anaerobic metabolism. Variables were well defined, and their communalities ranged from .70 to .94. In addition, based on the loading of variables on the 6 components, the percentage of cumulative variance explained 85.2% of the performance score.

A multiple-regression procedure was used to determine which components were significant predictors of rhythmic gymnastics performance-ranking score (Table 3). Correlation coefficients between the 6 factors and the performance-ranking score revealed that, in the total sample, anthropometric and aerobic-capacity components were significantly related to performance (component 1, \( R = .50 \), component 4, \( R = .74; P < .01 \)). The standardized \( \beta \) coefficient indicated that only 2 components made a significant contribution to the prediction model (Table 3). The anthropometric component had the largest \( \beta \) coefficient \( (\beta = 0.50) \), which indicated the largest contribution to the regression model, followed by the component of aerobic capacity \( (\beta = 0.49) \).

A multiple-regression analysis was also applied with elite and nonelite rhythmic gymnasts separately. The data analysis showed that 92.5% of the variations in elite gymnasts’ performance \((y)\) was explained by absolute VO\(_2\)max \((58.9\%)\), arm span \((12\%)\), mid thigh circumference \((13.1\%)\), and body mass \((8.5\%)\). The model identified a high VO\(_2\)max \((\text{L/min})\) as the first predictor of performance score in elite
<table>
<thead>
<tr>
<th>Anthropometric measurement</th>
<th>Independent t Tests</th>
<th>Correlations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Elite (n = 15)</td>
<td>Nonelite (n = 19)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>151.06 ± 9.5</td>
<td>152.84 ± 7.52</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>35.60 ± 5.46</td>
<td>38.36 ± 5.81</td>
</tr>
<tr>
<td>Arm span (cm)</td>
<td>155.95 ± 7.79</td>
<td>155.80 ± 10</td>
</tr>
<tr>
<td>Arm span and height index</td>
<td>1.03 ± 0.02</td>
<td>1.01 ± 0.03</td>
</tr>
<tr>
<td>Sitting and standing height ratio</td>
<td>51.25 ± 1.48</td>
<td>51.25 ± 1.48</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>13.97 ± 2.18</td>
<td>14.32 ± 2.73</td>
</tr>
<tr>
<td>Lean body weight (kg)</td>
<td>29.84 ± 1.81</td>
<td>28.86 ± 1.27</td>
</tr>
<tr>
<td>Biacromial breadth (mm)</td>
<td>33.91 ± 2.02</td>
<td>34.38 ± 2.30</td>
</tr>
<tr>
<td>Chest breadth (mm)</td>
<td>21.10 ± 1.62</td>
<td>21.64 ± 2.20</td>
</tr>
<tr>
<td>Biliac breadth (mm)</td>
<td>22.32 ± 1.98</td>
<td>23.57 ± 1.75</td>
</tr>
<tr>
<td>Bitrochanteric breadth (mm)</td>
<td>25.06 ± 2.33</td>
<td>25.55 ± 2.15</td>
</tr>
<tr>
<td>Shoulder circumference (cm)</td>
<td>83.36 ± 4.85</td>
<td>84.89 ± 5.83</td>
</tr>
<tr>
<td>Chest circumference (cm)</td>
<td>65.90 ± 4.38</td>
<td>68.62 ± 4.92</td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td>53.92 ± 2.94</td>
<td>54.92 ± 2.84</td>
</tr>
<tr>
<td>Abdominal circumference (cm)</td>
<td>55.67 ± 3.01</td>
<td>57.13 ± 4.00</td>
</tr>
<tr>
<td>Hip circumference (cm)</td>
<td>71.5 ± 5.81</td>
<td>73.83 ± 5.85</td>
</tr>
<tr>
<td>Proximal thigh circumference (cm)</td>
<td>40.62 ± 3.27</td>
<td>41.76 ± 3.12</td>
</tr>
<tr>
<td>Midtigh circumference (cm)</td>
<td>37.24 ± 2.30</td>
<td>37.98 ± 2.74</td>
</tr>
<tr>
<td>Calf circumference (cm)</td>
<td>28.23 ± 1.83</td>
<td>28.66 ± 1.94</td>
</tr>
<tr>
<td>Arm circumference (cm)</td>
<td>18.52 ± 1.09</td>
<td>18.85 ± 1.79</td>
</tr>
</tbody>
</table>

*P < .05. **P < .01. ***P < .001.
Table 2  Results (mean ± SD) of Independent \(t\) Tests and Correlation Coefficients of Physiological and Physical Fitness Measurements With Performance Score

<table>
<thead>
<tr>
<th>Fitness measurement</th>
<th>Elite ((n = 15))</th>
<th>Nonelite ((n = 19))</th>
<th>Correlations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximal oxygen-consumption test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\text{VO}_2\text{max (mL/min)})</td>
<td>1943.5 ± 252.85(^a)</td>
<td>1721.9 ± 254.2</td>
<td>.77** (\ldots)</td>
</tr>
<tr>
<td>(\text{VO}_2\text{max (mL·min}^{-1}·\text{kg}^{-1}))</td>
<td>54.81 ± 2.64(a)</td>
<td>45.10 ± 4.21</td>
<td>-.18</td>
</tr>
<tr>
<td>heart rate (beats/min)</td>
<td>193.26 ± 9.23(\ldots)</td>
<td>184.73 ± 10.73</td>
<td>-.47</td>
</tr>
<tr>
<td>blood lactate (mmol/L)</td>
<td>8.91 ± 2.47</td>
<td>8.60 ± 2.11</td>
<td>.30</td>
</tr>
<tr>
<td>ventilation (L/min)</td>
<td>61.60 ± 6.45</td>
<td>56.68 ± 9.53</td>
<td>.54*</td>
</tr>
<tr>
<td>respiratory-exchange ratio</td>
<td>1.09 ± 0.05</td>
<td>1.10 ± 0.05</td>
<td>.31</td>
</tr>
<tr>
<td>(\text{O}_2\text{pulse (mL)})</td>
<td>10.1 ± 1.84</td>
<td>9.65 ± 1.67</td>
<td>.76**</td>
</tr>
<tr>
<td>exercise time (min)</td>
<td>14.90 ± 2.64</td>
<td>13.40 ± 3.01</td>
<td>.84**</td>
</tr>
<tr>
<td>Physical fitness measurements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sprint test (s)</td>
<td>5.45 ± 0.19</td>
<td>5.50 ± 0.28</td>
<td>-.40</td>
</tr>
<tr>
<td>sit-ups (s)</td>
<td>38.78 ± 3.04</td>
<td>38.67 ± 3.59</td>
<td>.15</td>
</tr>
<tr>
<td>standing long jump (cm)</td>
<td>173.05 ± 14.6</td>
<td>171.07 ± 16</td>
<td>.50</td>
</tr>
<tr>
<td>vertical jump (cm)</td>
<td>37.53 ± 3.48</td>
<td>35.94 ± 3.50</td>
<td>.29</td>
</tr>
<tr>
<td>sit-and-reach test (cm)</td>
<td>22.16 ± 3.53</td>
<td>23.55 ± 4.50</td>
<td>.52*</td>
</tr>
<tr>
<td>shoulder flexibility test (cm)</td>
<td>16 ± 11.48</td>
<td>17.31 ± 12.70</td>
<td>-.16</td>
</tr>
<tr>
<td>side splits with right leg forward (cm)</td>
<td>50.77 ± 9.51(a)</td>
<td>42.27 ± 14.56</td>
<td>-.05</td>
</tr>
<tr>
<td>side splits with left leg forward (cm)</td>
<td>33.80 ± 12.44</td>
<td>31.97 ± 12.60</td>
<td>.46</td>
</tr>
<tr>
<td>right-leg lift test forward (°)</td>
<td>170.53 ± 10.25</td>
<td>164 ± 14.76</td>
<td>.19</td>
</tr>
<tr>
<td>left-leg lift test forward (°)</td>
<td>150.26 ± 17</td>
<td>148.94 ± 16.5</td>
<td>.64**</td>
</tr>
<tr>
<td>right-leg lift test sideward (°)</td>
<td>173.60 ± 13.04(\ldots)</td>
<td>162.57 ± 14.42</td>
<td>.24</td>
</tr>
<tr>
<td>left-leg lift test sideward (°)</td>
<td>153.66 ± 18.63</td>
<td>149.42 ± 14.41</td>
<td>.44</td>
</tr>
</tbody>
</table>

\(^a\) Significantly different from nonelite, \(\text{VO}_2\text{max (P < .001)}, \) heart rate, side splits with right leg forward, leg-lift test sideward \((P < .05)\).

*\(P < .05\).*  **\(P < .01\).*  ***\(P < .001\).*
Figure 1 — Relationship between VO$_{2max}$ and rhythmic gymnastics performance-ranking score in total sample, in elite rhythmic gymnasts, and in nonelite rhythmic gymnasts.
gymnasts \((R = .77, F_{1,13} = 18.65, P < .001, \text{SEE} = 1.070)\) and led to the following equation:

\[
y = -10.708 + (0.0005121 \times \text{VO}_2\text{max}) + (0.157 \times \text{arm span}) + (0.814 \times \text{midthigh circumference}) - (0.293 \times \text{body mass}).
\]

### Discussion

According to the PCA procedure applied in the current study, successful performance in rhythmic gymnastics depends on 6 components: anthropometric characteristics, flexibility, explosive strength, aerobic capacity, body dimensions, and anaerobic metabolism. Knowledge of the importance of these components is helpful for coaches who invest time and effort to succeed in a very demanding discipline. One of the major findings, however, is that rhythmic gymnastics performance-ranking scores can be significantly explained by anthropometric and aerobic-capacity components, and it should be noted that the latter was identified as the first predictor in elite rhythmic gymnastics athletes.

The anthropometric component has the largest amount of cumulative variance in the PCA model (45%) and includes height, body mass, arm span, circumferences, and diameters. Indeed, the appearance and the aesthetic standards of body shape in rhythmic gymnasts entail a better execution of gymnastic movements, which might also be more pleasing to the judges. In addition, having a low body mass appears to be an obvious advantage when performing skills that require movements with intricate routines. Furthermore, it has been reported that rhythmic gymnastics athletes have broad shoulders, narrow hips, long and slim upper and lower limbs,
and very low body fat and show symmetrical values in the sitting and standing height ratio. These characteristics are in line with our data and seem to be important determinants for the quality of athletic performance.

It is important to point out that physiological and physical performance variables are frequently influenced by body size. During adolescence the increase in absolute VO$_2$max is associated with heart and body growth. Indeed, absolute VO$_2$max increases as a function of body size, whereas relative VO$_2$max remains stable in boys and declines in girls during adolescence. In addition, fat-free mass is an important determinant of heart size and heart growth for both boys and girls, but changes in aerobic fitness, most likely based on the improvements of cardiac function, also affect heart growth in boys. This probably indicates that the known age-related decrease in the ability of body size to predict heart size begins sooner in males than females. Girls who are gaining lean tissue demonstrate greater increases in heart size and thus greater absolute VO$_2$max. Our data showed that elite gymnasts with low body mass and similar absolute values of VO$_2$max are more efficient during competition than their nonelite coathletes. This observation reveals that body mass represents the volume of metabolically active tissue and reflects the differences in oxygen consumption, heart size, and various demanding movements required during a successful rhythmic gymnastics performance. Nevertheless, our elite gymnasts who gained more fat-free body mass reached higher absolute VO$_2$max and attained higher performance levels. In addition, the absolute VO$_2$max values are well correlated with performance score, whereas relative VO$_2$max is not. These observations might result from individual differences in the qualitative characteristics of body size and structure among athletes.

Although the aerobic-capacity component explained about 7.5% of the cumulative variance in the total sample, VO$_2$max alone explained 58.9% of the variance in elite rhythmic gymnasts. Previous research found very low correlations with performance in almost all variables of anthropometric and physiological characteristics apart from selected flexibility tests. Hume et al presented a more comprehensive range of potential predictors and stated that anthropometric features, flexibility, leg power, and visual-motor proficiency were significantly correlated with attainment ($r = .69$ to .29).

In our study, however, the multiple-regression analysis showed that the absolute value of VO$_2$max was the first predictor of attainment and was highly correlated with performance of elite gymnasts (Figure 1). This relationship clearly demonstrated the contribution of aerobic metabolism during the execution of rhythmic gymnastics routines. Indeed, competitive routines last about 60 to 90 seconds with each type of apparatus and usually combine elements that require high-intensity effort with a dexterous manipulation of the apparatus. These elements change very fast, and the working muscle cells use all energy systems to satisfy the demands in a variety of movements performed during competition. The statistical approach of our study highlights the significance of aerobic and anaerobic metabolism (high-energy phosphate and glycolysis) for successful performance. Even though energy contribution in rhythmic gymnastics routines has not been the focus of our study, it is clear that continuous maximal exercise for 60 to 90 seconds requires aerobic metabolism.

Coaches should consider the fact that gymnasts require anaerobic power, as well as aerobic capacity, to meet the energy demands and rapidly restore the
high-energy phosphate sources required during competitive routines. In agreement with our study, Guidetti et al. found that the most taxed energy source during the ball routine was aerobic, which enabled athletes to perform high-intensity rhythmic gymnastics routines and also pointed out the importance of anaerobic metabolism. There is a need, however, to examine the contribution of energy systems in detail during rhythmic gymnastics performance routines.

Based on the results of the PCA in the current study, flexibility and explosive strength were extracted from the original set of variables and explained about 12% and 9.2% of the cumulative variance of the model. Among the physical measurements, flexibility and jumping ability have been considered good determinants of performance, because routines are partly judged on the range of motion exhibited by the gymnasts in a variety of movements and explosive jumps. During performance, the range of movement surpasses the limits of physiological displacement of the limbs. This extreme range of motion should be performed aesthetically, smoothly, and efficiently within the rhythm of music. Therefore, a combination of strength and flexibility is important for a high-quality performance.

The development of flexibility should coincide with that of strength to support the joints. For example, it takes a certain amount of strength for an athlete to swing a prevalent leg during a jump (e.g., grand-jete en cloche), but it takes muscle endurance to repeat these movements often during the 3 to 4 hours of regular training. Therefore, the development of gymnasts’ strength and flexibility is among of the most important factors of success, as is also supported in most studies. Generally, rhythmic gymnastics requires the use of a considerable degree of flexibility and strength and demands a high degree of development in these specific components. The development of strength and flexibility might allow gymnasts to perform more skillfully by increasing the height and length of jumps and leaps in different routines. Thus, specific physical preparation helps gymnasts develop and maintain their physical abilities, which are necessary for a successful technical performance in rhythmic gymnastics.

In conclusion, within the limitations of our study (small number of elite athletes and investigation of a complex and demanding sport), our results revealed that anthropometric characteristics, flexibility, explosive strength, aerobic capacity, body dimensions, and anaerobic metabolism are important factors and lead to better execution of gymnastic routines. The significant correlation of these determinants with performance supports the need to include in talent detection such criteria that emphasize certain anthropometric characteristics, as well as VO$_2$max, which is genetically determined and adds another dimension to rhythmic gymnastics training. An initial adequate level of aerobic capacity offers an advantage to young gymnasts, and regular endurance training is required to tolerate strenuous exercise. Aerobic capacity, however, although it was directly determined in our study, can also be easily estimated from the 20-m shuttle-run field test, a practical, valid, and reliable test with available norms that does not require complex laboratory equipment and has been used extensively by many investigators. Moreover, rhythmic gymnastics performance, except for aerobic capacity, requires additional specific skills with apparatuses, such as technical dexterity, static and dynamic balance, and eye–hand coordination, that were not examined in the current study. Nevertheless, coaches should be aware of these specific attributes to improve talent identification and training of rhythmic gymnasts.
References


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