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# Evaluating the physical and basic gymnastics skills assessment for talent identification in men's artistic gymnastics proposed by the International Gymnastics Federation

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**ABSTRACT:** This study aimed to determine the specific physical and basic gymnastics skills considered critical in gymnastics talent identification and selection as well as in promoting men's artistic gymnastics performances. Fifty-one boys from a provincial gymnastics team (age 11.03 ± 0.95 years; height 1.33 ± 0.05 m; body mass 30.01 ± 5.53 kg; body mass index [BMI] 16.89 ± 3.93 kg/m$^2$) regularly competing at national level voluntarily participated in this study. Anthropometric measures as well as the men's artistic gymnastics physical test battery (i.e., International Gymnastics Federation [FIG] age group development programme) were used to assess the somatic and physical fitness profile of participants, respectively. The physical characteristics assessed were: muscle strength, flexibility, speed, endurance, and muscle power. Test outcomes were subjected to a principal components analysis to identify the most representative factors. The main findings revealed that power speed, isometric and explosive strength, strength endurance, and dynamic and static flexibility are the most determinant physical fitness aspects of the talent selection process in young male artistic gymnasts. These findings are of utmost importance for talent identification, selection, and development.

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## INTRODUCTION

Artistic gymnastics (AG) is a type of power speed activity that requires high levels of both anaerobic and flexibility capacities for successful performance [1]. It promotes jumping, pushing, explosive strength, and pulling skills development together with balance and artistry on the different apparatuses [2-5]. Artistic gymnastics performance depends on the perfect trade-off between the physical fitness level and the complex technical skills required on each apparatus [6]. Thus, a high fitness performance level is decisive in men's artistic gymnastics (MAG) to fulfil exercises' technical requirements on different apparatuses [7]. Specifically, the gymnast must achieve high strength, flexibility, and coordination levels to effectively perform the wide range of complex acrobatic skills [8-12]. Bencke et al. [13] indicated that gymnastic athletes develop better lower limb strength indices at an early age compared with practitioners of other sports (e.g., handball, tennis, swimming). The same authors were able to demonstrate that 11-year-old male gymnasts were stronger than their untrained peers. It is noteworthy that long-term gymnastics training has various effects depending on the type of strength indices (i.e., rate of force development, maximal, relative and absolute force) [14, 15] as well as the particular muscle groups (i.e., lower and upper limbs) [16, 17]. Accordingly, previous research [14, 17] showed a higher rate of force development in young gymnasts compared to their untrained peers.

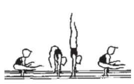
Talent identification (i.e., the process of recognizing current participants with promising capacities to excel in a particular sport) is a fundamental process in the pursuit of sports performance excellence [18]. It is worth noting that in both team and individual sports, widely accepted talent identification models are still limited [19]. In artistic gymnastics, particularly, some models/programmes of talent identification are emerging in leading countries (e.g., International Gymnastics Federation [FIG] Age Group Development Programme, USA Gymnastics TOPs programme, Gymnastics Functional Measurement Tool [GFMT], and World Identification Systems for Gymnastics Talent [WISGT]). The most accepted programmes used by coaches and researchers are those of the International Gymnastics Federation and the USA Gymnastics [1, 5, 20-26].

The training and talent identification programme of the International Gymnastics Federation "FIG MAG Age Group Development

Program" [27, 28] presents the basic approach adopted to develop young gymnasts' physical fitness (i.e., strength, flexibility, power, and endurance). This programme is currently adopted by FIG international coaches for young (i.e., 6-11 years) and 18-year-old gymnasts [16]. Accordingly, gymnasts must be prepared gradually over several years to sustain and develop their physical fitness performance required to succeed in competition [27, 28]. The FIG is working vigorously on improving and updating the training and talent identification programme. Additionally, the education of coaches to improve their knowledge and effectiveness in physical, technical, and psychological preparation, without causing harm to gymnasts' health, is one of the main missions of FIG [27, 28].

The FIG MAG Age Group Development Program [27] has been previously validated [5, 29]. It is considered a useful tool for gymnastics talent identification [5, 29]. In fact, high-level gymnastics performance requires long-term systematic physical fitness preparation. Therefore, it is crucial to quantify the physical progress achieved and to distinguish, among the gymnasts already selected for national competitions, those most likely to achieve good performance at international competitive MAG events. Thus, it would be interesting to obtain 'cross-cultural' data about these variables from early phases of training. In other words, a thoughtful assessment of young gymnasts' physical abilities from an early age is critical for a future successful career.

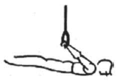
**TABLE 1.** Men's artistic gymnastics physical profile assessment [27].

| Test (description) | Diagrams | Target | Condition | FIG values | Gymnasts, mean ± SD | Z test | *d* |
|---|---|---|---|---|---|---|---|
| 20 m run (standing start) |  | Power Speed | Velocity (s) | 4.00 | 3.66 ± 0.23 | 0.001 | 1.478 |
| 4 m rope climb (legs assisted) |  | Power Speed | Strength / Coordination (s) | 5.60 | 14.62 ± 8.28 | 0.001 | 1.089 |
| Vertical jump (from a standing position) |  | Power Speed | Strength / Coordination (cm) | 40 | 40.97 ± 5.13 | 0.292 | 0.189 |
| Broad jump (from a standing position) |  | Power Speed | Velocity / Coordination (cm) | 200 | 179.68 ± 19.02 | 0.001 | 1.068 |
| Flexion legs upon upper body (from hang on wall bar) |  | Dynamic Strength | Speed (Reps·30 $s^{-1}$) | 33 | 13.39 ± 4.59 | 0.001 | 4.272 |
| Extension legs upon upper body (from front support) |  | Dynamic Strength | Speed (Reps·30 $s^{-1}$) | 33 | 23.97 ± 3.39 | 0.001 | 2.663 |
| Pull up (on high bar: arms fully extended; shoulder level with bar) |  | Dynamic Strength | Endurance (Reps) | 9 | 13.10 ± 6.13 | 0.001 | 0.668 |
| Dips (on parallel bars: body vertical, arms stretched in support) |  | Dynamic Strength | Endurance (Reps) | 10 | 18.87 ± 8.10 | 0.001 | 1.095 |
| Straddle lift to handstand (body bent, arms and legs) |  | Strength Coordination | Endurance (Reps) | 8 | 7.03 ± 3.07 | 0.079 | 0.315 |

Legend: (d) effect size; d < 0.2 (trivial); 0.2–0.6 (small); 0.6–1.2 (moderate); 1.2–2.0 (large); and > 2.0 (very large).

In the literature, several studies [1, 5, 20-26] have investigated talent identification in women artistic gymnastics (WAG), including a recently published study by Nassib et al. [20] on prediction of the women artistic gymnastics (WAG) physical fitness profile through the international evaluation programme "FIG Age Group Development" [27]. The main findings of this study were that elite level female gymnasts present greater muscular strength in its different forms (i.e., isometric, explosive, and endurance), power, and flexibility compared to the FIG [27] standards. The same authors revealed that these fitness qualities represent the main physical fitness factors determining success in WAG. However, similar studies concerning men's artistic gymnastics (MAG) are scarce [5, 29]. For instance, Sleeper et al. [5] studied different age group categories based on the Men's Gymnastics Functional Measurement Tool (MGFMT). The authors used ten MGFMT battery tests on a large sample (i.e., 83 gymnasts between 8.3 ± 1.3 and 16.2 ± 1.1 years, each age group containing 6 to 20 gymnasts) of different levels of practice. The findings of the study [5] proved good reliability and construct validity of the MGFMT battery. In the same context, Leon-Prados et al. [29] studied the relationship between specific physical fitness tests and the gymnastics performance score (i.e., sum of the points of the six apparatus) in high-level male gymnasts. The authors used six tests, including four tests of flexibility (i.e., static and dynamic). The main outcomes of this study showed significant relationships between the

**TABLE 1.** *continued*

| Test (description) | Diagrams | Target | Condition | FIG values | Gymnasts, mean ± SD | Z test | *d* |
|---|---|---|---|---|---|---|---|
| Double legs circle (on mushroom) |  | Endurance | Coordination Endurance (Reps) | 30 | 26.81 ± 6.55 | 0.283 | 0.484 |
| V lever (legs to or over vertical) |  | Static Strength | Isometric Coordination (s) | 5 | 5.65 ± 2.70 | 0.608 | 0.240 |
| Tucked top planche (body horizontal through shoulder, arms stretched) |  | Static Strength | Isometric Coordination (s) | 10 | 18.76 ± 7.59 | 0.001 | 1.154 |
| Back hang scale (body horizontal, legs and arms stretched) |  | Static Strength | Isometric Coordination (s) | 4 | 4.57 ± 3.23 | 0.541 | 0.176 |
| Side split sit |  | Flexibility | Static (°) | 180 | 175.48 ± 17.14 | 0.142 | 0.263 |
| Right split sit |  | Flexibility | Static (°) | 180 | 172.26 ± 15.38 | 0.005 | 0.503 |
| Left split sit |  | Flexibility | Static (°) | 180 | 173.87 ± 13.15 | 0.009 | 0.466 |
| Bridge (on hard mats) |  | Flexibility | Static (°) | 90 | 82.42 ± 11.68 | 0.001 | 0.648 |
| Body bent (on the bench) |  | Flexibility | Static (cm) | 20 | 13.48 ± 3.41 | 0.001 | 1.969 |
| Leg lift forwards (with the back on the wall) |  | Flexibility | Dynamic (°) | 120 | 99.35 ± 13.09 | 0.001 | 1.577 |
| Active shoulder flexibility |  | Flexibility | Dynamic (cm) | 50 | 45.98 ± 12.52 | 0.075 | 0.321 |

final scores achieved for the pommel horse, parallel bars, and horizontal bar with strength and flexibility performance. To the authors' knowledge, only the study of Sleeper et al. [5] was conducted in a large sample of young male gymnasts (i.e., 73 young and 10 adult gymnasts). In the study of Leon-Prados et al. [29], only 11 adult male gymnasts were included. However, both studies [5, 29] focused on limited physical fitness tests (i.e., 6 to 10 tests). Additionally, the process of talent identification in the two above-mentioned studies [5, 29] was not sufficiently addressed. Therefore, the aim of this study was to determine the specific physical and basic gymnastics skills considered critical in the identification and selection of gymnastics' talent and in optimizing men's artistic gymnastics performances.

## MATERIALS AND METHODS

### *Participants*

The study was performed in accordance with the Declaration of Helsinki for human experimentation and was approved by the local ethical committee of the respective department before starting the measurements. Fifty-one young male artistic gymnasts from a provincial team (age 11.03 ± 0.95 years; height 1.33 ± 0.05 m; body mass 30.01 ± 5.53 kg; body mass index [BMI] 16.89 ± 3.93 kg/m$^2$) regularly competing at national level voluntarily participated in this study. Their average training experience was 6 ± 1 years and the average duration of their weekly training was 20 ± 2 h (two sessions per day for 5 days per week). The peak height velocity (PHV) and the maturity offset (MO) of participants were assessed using a previously validated equation (MO = -7.999994 + (0.0036124 × age × height); $R^2$ = 0.896 and SEE = 0.542) [30]. The results showed that the maturation level of participants was prepubertal (MO = -2.27 ± 0.7 years; 95% CI: -1.23 to -3.22). The ages were stored according to the year of birth, as pre-determined by the official categories of FIG age group [27]. They were therefore given detailed instructions on how to perform the physical and technical exercise accurately and efficiently. Written informed parental consent and participant assent were obtained prior to the start of the study. All youth athletes and their parents/legal representatives were informed about the experimental protocol and its potential risks and benefits before the commencement of the research project.

It is important to note that the first targeted sample size was 131 gymnasts. However, after applying strict inclusion criteria including regular participation in gymnastics national level competitions, ranking in the top scorers at the last provincial and national championship, and being involved in the FIG MAG Age Group Development Program [27] during their regular training programme, 80 gymnasts were excluded.

### *Procedures*

Standardized instructions and verbal encouragements were provided to participants during all the experimental sessions. They were also asked to avoid high-intensity physical training for 48 h preceding the testing sessions. This aimed to prevent the influence of residual fatigue from interfering with the test performance. The experiment included two phases. The first phase was a contact session, while the second one corresponded to the experimental session.

Contact Session. Participants' personal information such as name, age, and address was collected during this session. All of the gymnasts were made familiar with the procedures of testing. Prior to performing the FIG test battery [27], gymnasts were given a standardized set of instructions explaining the different tests. Thereafter, they were familiarized with the experimental apparatus. Gymnasts were asked to avoid high-intensity physical training for 48 h before the simulated competition condition.

An interview was conducted with coaches of regional men's teams to identify the strategies most often adopted to establish a profile of the gymnast that respects elite performance needs. The interview highlighted that age group, specific skills (i.e., physical traits), and psychological characteristics (e.g., personality traits) are the main criteria that coaches worked with for men's artistic gymnastics talent selection. Additionally, coaches were asked whether they applied the international physical fitness testing battery in the teams they had been working for. Only 4 out of 12 coaches responded that they were considering the international physical fitness testing battery during their training programmes.

Experimental Sessions. During the experimental sessions, all participants completed a standardized warm-up that included jogging for several laps (~5 min) around the floor space, different jumps (~5 min) and stretching of the major lower (e.g., leg, thigh, gluteus region) and upper (e.g., chest, shoulder, arm) limb muscles (~5 min). Then, they received specific instructions delivered according to the assigned condition and they were asked to achieve their highest performance in the different assessments undertaken.

The methodological control of the protocol was assured by three steps. First, 48 h separated the experimental sessions to avoid any order or fatigue effect which could be experienced by the participants. Second, none of them had consciously performed physical fitness tests to improve performance before engaging in the protocol. This was checked by an individual interview. Third, subjects had to wear the same clothes during each session, to abstain from having hard training sessions on the day before each testing session, and to maintain a consistent dietary intake on each testing day. The same testers (i.e., two highly qualified international gymnastics coaches) conducted all the experimental sessions and provided consistent recommendations and encouragement to the gymnasts. Each test was performed twice, and the best performance was selected for further analyses. To account for diurnal variation, participants were assessed at the same time of day (between 9.00 AM and 11.30 AM). Temperature and relative humidity were 22 ± 1°C and 43 ± 1%, respectively. Subjects were healthy without any muscular, neurological or tendon injuries. No medical problem appeared during the study.

**TABLE 2.** Reliability analysis of MAG battery [27].

| Test | Test vs. retest (mean ± SD) | T-test | P | TEM | TEM(%) | ICC (95% CI) | d |
|---|---|---|---|---|---|---|---|
| 20 m run | 3.66 ± 0.23 m·s$^{-1}$<br>3.67 ± 0.22 m·s$^{-1}$ | -0.918 | 0.366 | 0.001 | 0.084 | 0.996 (0.993-0.998) | 0.014# |
| 4 m rope climb | 14.76 ± 8.27 s<br>14.74 ± 8.16 s | -1.881 | 0.070 | 0.008 | 0.019 | 0.999 (0.997-0.999) | 0.014# |
| Vertical jump | 40.86 ± 5.07 cm<br>40.93 ± 5.12 cm | -1.603 | 0.120 | 0.001 | 0.005 | 0.999 (0.997-0.999) | 0.001# |
| Broad jump | 179.03 ± 18.93 cm<br>178.81 ± 18.73 cm | 0.684 | 0.499 | 0.127 | 0.073 | 0.995 (0.990-0.998) | 0.008# |
| Flexion legs upon upper body | 13.26 ± 4.58 Reps<br>13.03 ± 4.44 Reps | 1.880 | 0.070 | 0.052 | 0.394 | 0.994 (0.987-0.997) | 0.049# |
| Extension legs upon upper body | 23.65 ± 3.46 Reps<br>23.52 ± 3.41 Reps | 0.661 | 0.514 | 0.172 | 0.729 | 0.975 (0948-0988) | 0.037# |
| Pull up | 13.00 ± 6.06 Reps<br>13.10 ± 6.13 Reps | -1.793 | 0.083 | 0.010 | 0.073 | 0.999 (0.997-0.999) | 0.016# |
| Dips | 18.55 ± 7.91 Reps<br>18.61 ± 7.86 Reps | -0.387 | 0.702 | 0.078 | 0.0418 | 0.993 (0.986-0.997) | 0.008# |
| Straddle lift to handstand | 6.87± 3.00 Reps<br>6.90 ± 2.96 Reps | -0.329 | 0.745 | 0.049 | 0.710 | 0.992 (0.983-0.996) | 0.011# |
| Double legs circle | 26.29 ± 16.17 Reps<br>26.68 ± 16.72 Reps | -1.139 | 0.264 | 0.104 | 0.391 | 0.997 (0.993-0.998) | 0.024# |
| V lever | 5.64 ± 2.72 s<br>5.61 ± 2.69 s | 1.956 | 0.060 | 0.001 | 0.010 | 0.999 (0.997-0.999) | 0.001# |
| Tucked top planche | 18.71 ± 7.58 s<br>18.66 ± 7.57 s | 1.515 | 0.140 | 0.006 | 0.033 | 0.999 (0.997-0.999) | 0.007# |
| Back hang scale | 4.45 ± 5.22 s<br>4.49 ± 5.19 s | 1.146 | 0.261 | 0.008 | 0.178 | 0.999 (0.998-0.999) | 0.010# |
| Side split sit | 175.48 ± 17.14 °<br>175.00 ± 17.13 ° | 1.793 | 0.083 | 0.095 | 0.054 | 0.998 (0.996-0.999) | 0.028# |
| Right split sit | 171.77 ± 15.09 °<br>171.29 ± 15.11 ° | 1.000 | 0.325 | 0.241 | 0.140 | 0.992 (0.983-0.996) | 0.032# |
| Left split sit | 173.71 ± 13.10 °<br>172.74 ± 12.44 ° | 1.793 | 0.083 | 0.368 | 0.212 | 0.985 (0.968-0.993) | 0.074# |
| Bridge | 81.94 ± 11.01 °<br>81.45 ± 11.27 ° | 1.000 | 0.325 | 0.330 | 0.404 | 0.985 (0.969-0.993) | 0.044# |
| Body bent | 13.29 ± 3.39 cm<br>13.26 ± 3.42 cm | 0.254 | 0.801 | 0.074 | 0.558 | 0.989 (0.978-0.995) | 0.010# |
| Leg lift forwards | 98.26 ± 3.42 °<br>98.23 ± 12.62 ° | 0.421 | 0.677 | 0.764 | 0.776 | 0.968 (0.934-0.985) | 0.028# |
| Active shoulder flexibility | 45.58 ± 12.12 cm<br>45.29 ± 12.51 cm | 0.987 | 0.331 | 0.104 | 0.228 | 0.996 (0.991-0.998) | 0.024# |

Legend: (TEM) typical error of measurement; (ICC) intra-class correlation coefficient; (d) effect size; (#) trivial effect size.

After the completion of all the testing sessions, all participants received feedback regarding their individual outcomes.

### *Research Design*

To evaluate and identify the physical profile of young men's artistic gymnasts, an international model which was developed by a number of experts and scientists involved in the study and whose aim was to ensure a systematic approach for MAG development worldwide was used [27].

The FIG test battery was administered to evaluate gymnasts' physical fitness performance. The physical characteristics assessed were: strength, flexibility, speed, endurance, and power. All tests were applied on the same day. To maintain gymnasts' physical fitness and to avoid any overloading risk, it is advisable that strength and power activities should be organized in rotation per muscle group, always following the same application order: flexibility exercises, speed and power exercises, strength and endurance exercises. A summary of the testing procedure is displayed in Table 1.

### *Statistical Analyses*

Data are presented as mean ± standard deviation (SD) and confidence intervals at the 95% level (95% CI). The normality of distribution, estimated by the Kolmogorov-Smirnov test, was acceptable for all variables. The comparison of the averages calculated with theoretical references (i.e., FIG's values) was established by the z-test

$$z = \frac{m - \mu_0}{\frac{\sqrt{S^2}}{n}} .$$

**TABLE 3.** Factor loadings (varimax) – analysis of main components.

| Variables | Factor 1 | Factor 2 | Factor 3 | Factor 4 | Factor 5 | Factor 6 |
|---|---|---|---|---|---|---|
| 20 m run | **-0.84** | -0.17 | -0.06 | 0.03 | 0.09 | 0.06 |
| 4 m rope climb | **-0.80** | 0.11 | -0.14 | -0.10 | 0.10 | 0.04 |
| Vertical jump | **0.80** | -0.01 | 0.30 | -0.29 | 0.22 | 0.01 |
| Broad jump | **0.70** | -0.05 | 0.36 | -0.46 | 0.01 | -0.09 |
| Extension legs upon upper body | **0.64** | -0.14 | 0.32 | -0.23 | 0.03 | 0.40 |
| Active shoulder flexibility | **0.55** | -0.49 | 0.11 | -0.37 | 0.13 | 0.13 |
| Right split sit | -0.25 | **-0.79** | 0.09 | 0.27 | 0.34 | 0.06 |
| Back hang scale | 0.16 | **0.78** | -0.08 | 0.33 | -0.13 | -0.18 |
| V Lever | -0.32 | **0.76** | 0.10 | 0.18 | 0.45 | -0.10 |
| Tucked top planche | -0.31 | **0.75** | 0.20 | 0.21 | 0.39 | -0.07 |
| Dips | 0.25 | 0.17 | **0.91** | 0.01 | -0.03 | 0.01 |
| Pull ups | 0.09 | -0.05 | **0.90** | 0.16 | -0.01 | 0.14 |
| Double legs circles | 0.29 | -0.08 | **0.79** | -0.08 | -0.02 | -0.01 |
| Straddle lift to handstand | -0.19 | 0.17 | -0.03 | **0.91** | 0.16 | 0.07 |
| Flexion legs upon upper body | -0.17 | 0.18 | 0.23 | **0.83** | 0.33 | 0.06 |
| Leg lift forwards | -0.11 | 0.17 | 0.07 | -0.05 | **0.84** | 0.20 |
| Body bent | 0.06 | -0.09 | -0.07 | 0.32 | **0.70** | 0.11 |
| Bridge | 0.37 | -0.24 | -0.29 | 0.36 | **0.66** | 0.12 |
| Side split sit | 0.13 | -0.21 | 0.09 | 0.03 | 0.13 | **0.86** |
| Left split sit | -0.13 | -0.04 | 0.01 | 0.09 | 0.16 | **0.82** |
| **Eigenvalue** | **7.16** | **5.46** | **5.13** | **5.29** | **4.93** | **3.57** |
| **Cumulative percentage of total variation** | **19.39** | **34.04** | **48.15** | **60.78** | **72.68** | **81.43** |

Legend: (Factor 1) power speed; (Factor 2) isometric strength; (Factor 3) dynamic strength; (Factor 4) strength endurance; (Factor 5) dynamic flexibility; (Factor 6) static flexibility.

Thereafter, the outcomes of the test battery were introduced in an analysis of principal components (PCA) with the purpose of identifying the most representative factors. The factorial analysis began by calculation of the correlation matrix between tests assessed with the coefficient of determination ($R^2$). This matrix was submitted for extraction of the main components, followed by varimax rotation [31]. The factors were retained only if they were composed of two or more variables. Moreover, the first factor should be concentrated with the greatest part of the tests with factorial weight above 0.70 (i.e., the cutting point adopted for the definition of the connection force between tests) [20, 31]. A stepwise regression was established between the total apparatus score and physical parameters. In addition, we used the equation $f^2 = R^2 / (1 - R^2)$ to calculate the multiple regression effect size [32]. The following scale was used to interpret the effect size: $f^2 \geq 0.02$ small, $f^2 \geq 0.15$ medium and $f^2 \geq 0.35$ large. The relative and absolute reliability of the MAG battery were examined using the intra-class correlation coefficient (ICC) and the typical error of measurement (TEM) expressed as the coefficient of variation (CV), respectively. A paired sample t test was computed to assess any learning effect or systematic bias between sample mean scores for test and retest sessions. Significance was set at 0.5% ($p \leq 0.05$). Statistical analyses were performed using IBM SPSS Statistics Version 20 (IBM Corp., Armonk, New York, USA).

## RESULTS

The main results of the MAG battery are presented in Table 1. The sample of young gymnasts included in this study showed higher speed, strength endurance and static strength performance compared with FIG values ($p < 0.01$; d = 0.668 to 1.478). Endurance and power outcomes were comparable to the FIG values (i.e., double legs circle and vertical jump). Static and dynamic flexibility remained below the standard values ($p < 0.01$; d = 0.503 to 1.577). In addition, gymnasts showed higher technical scores according to the FIG rotation order as follow: 14.00 ± 2.51 points in the floor exercise, 13.58 ± 2.04 points in the pommel horse, 13.3 ± 3.04 points in the rings, 14.22 ± 2.15 points in the vault, 13.62 ± 2.01 points in the parallel bars, and 13.23 ± 2.29 points in the high bars. Accordingly, the total apparatus score (i.e., floor exercises, pommel horse, rings, vault, parallel bars and high bar) was 82.05 ± 12.88 points.

The reliability of the MAG age group battery is displayed in Table 2. The results showed good relative (ICC: 0.96 to 0.99) and absolute (TEM: 0.01% to 0.77%) reliability of the testing battery used.

The outcomes of the performed tests were subjected to PCA (Table 3). Six factors were retained for interpretation of the ratios between the battery tests applied (Eigen values > 1.0). Moreover, adopting 0.70 like a minimum correlation threshold, 17 physical fitness tests were retained from the whole MAG battery.

**TABLE 4.** Summary of the stepwise multiple regression between total apparatus scores and physical test.*

| Regression | $R^2$ | B | SE | Beta | t | P | Correlation | | Tolerance |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Simple | Partial | |
| (Constant) | | -15.260 | 10.899 | | -1.400 | 0.178 | | | |
| V Lever | 0.196 | 0.826 | 0.131 | 0.449 | 6.322 | 0.000 | 0.443 | 0.823 | 0.292 |
| Broad jump | 0.578 | 0.734 | 0.047 | 1.084 | 15.665 | 0.000 | 0.441 | 0.963 | 0.308 |
| Dips | 0.729 | -0.252 | 0.101 | -0.159 | -2.485 | 0.022 | 0.060 | -0.495 | 0.363 |
| 4m rope climb | 0.798 | 0.460 | 0.082 | 0.296 | 5.628 | 0.000 | 0.139 | 0.791 | 0.534 |
| Left split sit | 0.850 | -0.291 | 0.042 | 0-.297 | -6.972 | 0.000 | -0.370 | -0.848 | 0.813 |
| Bridge | 0.882 | 0.255 | 0.068 | 0.231 | 3.770 | 0.001 | 0.144 | 0.654 | 0.394 |
| Vertical jump | 0.912 | -0.807 | 0.178 | -0.321 | -4.533 | 0.000 | 0.154 | -0.721 | 0.294 |
| Body bent | 0.929 | -0.466 | 0.198 | -0.123 | -2.350 | 0.030 | 0.092 | -0.475 | 0.535 |
| Leg lift forward | 0.947 | 0.288 | 0.060 | 0.292 | 4.835 | 0.000 | 0.412 | 0.743 | 0.404 |
| Back hang scale | 0.965 | 0.476 | 0.124 | 0.193 | 3.843 | 0.001 | 0.355 | 0.661 | 0.586 |
| Double legs circles | 0.972 | -0.114 | 0.054 | -0.147 | -2.128 | 0.047 | 0.058 | -0.439 | 0.310 |

Legend: * Dependent variable: Total apparatus score; $p < 0.001$; r = 0.986; $R^2 = 0.972$; estimated standard error (ESE) = 2.711; effect size $f^2 = 34.641$.

The summary of the outcomes of the stepwise multiple regressions among the total apparatus scores and the physical tests are shown in Table 4.

The equation generated by the regression model to predict the total score was calculated as follows (equation 1).

**EQUATION 1.** Calculation of the total apparatus score from the physical fitness test battery for men's artistic gymnastics.

Total Apparatus Score =

$$= -15.26 + 0.826 \times (\text{V Lever}) + 0.734 \times (\text{Broad Jump}) - 0.252 \times (\text{Dips}) + 0.460 \times (\text{4 m Rope Climb}) - 0.291 \times (\text{Left Split Sit}) + 0.255 \times (\text{Bridge}) - 0.807 \times (\text{Vertical Jump}) - 0.466 \times (\text{Body Bent}) + 0.288 \times (\text{Leg Lift Forward}) + 0.476 \times (\text{Back Hang Scale}) - 0.114 \times (\text{Double Legs Circles})$$

## DISCUSSION

The current study is among the few that have studied MAG talent identification [5, 29]. To the authors' knowledge, this is the first study that has examined the specific physical and basic gymnastics skills of young men's artistic gymnasts through evaluation of an international programme (i.e., MAG FIG's age group evaluation programme) for talent identification purposes. The main findings of this study were that young male gymnasts achieved better scores in the speed, strength endurance and static strength tests than those indicated by the FIG [27] while power speed and endurance scores are comparable to those presented by the FIG [27]. In terms of static and dynamic flexibility, the present study's outcomes are still under the standard values of the FIG [27].

We note that the results of active shoulder flexibility and vertical jump are comparable to those presented by Sleeper et al. [5] and those of straddle lift to handstand are similar to the values reported by Leon-Prados et al. [29].

In this study, results of the principal component analysis (PCA) retained six principal factors that explained 81.43% of the total variance of all selected variables. These components are the power speed (19.39%), the isometric (14.65%) and the explosive (14.11%) strength, the strength endurance (12.63%), and the dynamic (11.90%) and the static flexibility (8.66%). Moreover, by adopting 0.70 like a minimum correlation threshold [31, 33], seventeen variables were retained from the FIG test battery. These variables are introduced in a stepwise multiple regression which identified eleven tests determinant of MAG performance: V lever, broad jump, dips, 4 m rope climb, left split sit, bridge, vertical jump, body bent, leg lift forward, back hang scale, and double legs circle.

This study conducted with young elite male gymnasts demonstrated that muscle power is paramount in identifying MAG talents. In this regards, Jemni et al. [12] showed that the strength and peak power are the main determinants of MAG gymnast's physiologic profile. In fact, the contribution of strength and power to men's gymnastics performance has increased during the last decades [12], given that most movements need to be performed with an explosive manner in a short-duration routine (5 seconds/70 seconds) [12]. In this context, Bencke et al. [13] indicated that gymnasts presented greater lower limb muscle power performance compared with tennis players, handball players, and swimmers. Jumping abilities have been shown to be the most important skill for MAG performance [13, 34]. This observation was highlighted by the superior jumping performance in elite compared with intermediate level gymnasts [14, 34]. In our study, gymnasts showed comparable vertical jumping performance to FIG values. However, horizontal jumping performance of young male gymnasts was lower than that of FIG [27]. Marina and Jemni [34] reported that a gymnast's jumping ability was associated with successful performance and can be considered as an overall indicator of gymnastics ability [35]. Furthermore, Brehmer and Naundorf [36] revealed that the run-up velocity is essential to enhance performance in artistic gymnastics, particularly in the vault event. In addition, previous evidence suggested that elite level male gymnasts are characterized by excellent lower and upper body muscular power [12, 37]. In this regard, strength and power are imperative in identification of MAG talents.

Measurement of gymnastics specific performance is important to determine progress and potential for gymnastics skills. In the rings, most skills are relatively slow moving or held (i.e., isometric). Therefore, the isometric component of strength is important for gymnasts [38]. Bernasconi et al. [39] showed that all top-level gymnasts perform the support scale at rings height. In addition, Bodray et al. [40, 41] suggested that the circle performed on the pommel horse is a sequence of complex movements in which the amplitude, governed by a high isometric strength level, is the key component of the performance.

Another quality that emerged from the results of the physical fitness profile is flexibility. This fitness quality was identified as one of the determinants of gymnastics performance. For instance, Sands et al. [42] reported that the flexibility level can be considered as one of the pillars of fitness characteristics in AG.

On the whole, developing various fitness traits (i.e., speed, power, strength endurance, and flexibility) seems to be very important for building elite men's gymnastics profile. For that reason, an objective assessment of young gymnasts (i.e., a valid test battery for each age group) is certainly required to identify potential future champions. However, longitudinal studies are still needed to determine whether the great disparity of physical fitness tests undertaken in this study would be effective in predicting future successful gymnasts.

Of note, the FIG battery lacks coordination tests. Therefore, it may be useful to include the battery Körperkoordinations Test für Kinder (KTK) adopted by Vandrope et al. [25] to discriminate female gymnasts by competitive level.

## CONCLUSIONS

The present findings outline the specific physical fitness performance factors considered critical in the detection, identification, development, and selection of gymnastics talent. These factors are strength, power, speed, and endurance. Furthermore, the results of the principal component analysis retained six principal components. These components are the power speed, isometric and explosive strength, strength endurance, and dynamic and static flexibility. These results seem to be tremendously important, because they support the increase in focus on power and difficulty in high-level gymnastics practice.

In this view, it is interesting to note that the rapid increase in the difficulty content of MAG performances has also been the result of the improved physical profile as well as of ever-increasing volume and intensity of training at ever-younger ages. Accordingly, proper talent identification should be intended to safely and systematically prepare young gymnasts for high performance below the junior level.

Taken together, coaches and strength and conditioning professionals should consider integrating the current physical fitness test battery in their development programmes with elite male young gymnastics to monitor and enhance their physical fitness performance. Overall, the MAG battery can be considered an effective tool to identify future talents in men's artistic gymnastics.

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**Conflict of interest**

There is no conflict of interest including any financial, personal or other relationships with other people or organizations that have influenced the performance of this work.

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