



The Physique of Elite Female Artistic Gymnasts: A Systematic Review

by

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It has been suggested that successful young gymnasts are a highly select group in terms of the physique. This review summarizes the available literature on elite female gymnasts' anthropometric characteristics, somatotype, body composition and biological maturation. The main aims were to identify: (i) a common physique and (ii) the differences, if any, among competitive/performance levels. A systematic search was conducted online using five different databases. Of 407 putative papers, 17 fulfilled all criteria and were included in the review. Most studies identified similar physiques based on: physical traits (small size and low body mass), a body type (predominance of ecto-mesomorphy), body composition (low fat mass), and maturity status (late skeletal maturity as well as late age-at-menarche). However, there was no consensus as to whether these features predicted competitive performance, or even differentiated between gymnasts within distinctive competitive levels. In conclusion, gymnasts, as a group, have unique pronounced characteristics. These characteristics are likely due to selection for naturally-occurring inherited traits. However, data available for world class competitions were mostly outdated and sample sizes were small. Thus, it was difficult to make any conclusions about whether physiques differed between particular competitive levels.

Key words: *anthropometry, somatotype, body composition, biological maturation, girls, gymnastics.*

Introduction

It has been suggested that successful young gymnasts are part of a highly select group in terms of specialized motor skills, body size and shape (Baxter-Jones et al., 2002). This likely reflects the interactions between varied environmental conditions and genetic endowments. As a group, they generally demonstrate growth characteristics associated with late-maturing girls. In terms of environmental settings, the prime conditions contributing to gymnast's success are thought to be family and peer support, training conditions, and continuous engagement in competitions, together with excellent coaching throughout their

career (Côté, 1999; Nunomura and Oliveira, 2013). Since anthropometric traits, somatotype, body composition and biological maturation characteristics help in predicting success in gymnastics competition (Baxter-Jones and Helms, 1996; Massidda et al., 2013), their use during the initial identification phase and in the monitoring of the training process is widespread (Massidda et al., 2013).

Available data indicate that, in general, gymnasts are shorter (in height) than their peers of the same chronological age, reach their predicted target adult heights, and have appropriate body composition as well as body

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mass for their maturity status (biological age); however, their pubertal maturation is somewhat late (Malina et al., 2013). Additionally, Malina et al. (2013) suggested that the effects of intensive training on female gymnasts' linear growth, if present, were almost negligible, although there is controversy around this (Baxter-Jones et al., 2003; Caine et al., 2003; Caine et al., 2001; Georgopoulos et al., 2004).

Studies on elite female gymnasts do not abound, especially those on elite gymnasts in various stages of their national/international careers (Pool et al., 1969). Nevertheless, available data typically comprise somatic profiles (Bester and Coetzee, 2010; Claessens et al., 1991), often in combination with biological maturation (Claessens et al., 1991, 2006; Georgopoulos et al., 2004; Peeters and Claessens, 2012), somatotype (Claessens et al., 1991; Massidda et al., 2013; Thorland et al., 1981) and body composition (Deutz et al., 2000; Theintz et al., 1981, 1989). Although there are numerous studies, no general consensus has been reached on how to report such data or how to construct multivariate profiles. Furthermore, there are always problems of small sample size and limited representativeness, the inclusion of different age groups, the use of different rating systems to classify gymnasts, diverse characteristics of their training loads, as well as the problem of how to link all these features to best characterize an elite gymnast. This is important if elite gymnasts are to be identified and tracked from an early age.

Although the physique is an important component, it has to be considered alongside individual's motor skills. Assessing motor abilities in such populations as of gymnasts is problematic given the vast array of methodology and expert opinions (Fink et al., 2008; USA-Gymnastics, 2014). The measurements are made difficult by including a number of complex parameters, such as wide variety in technical skills, muscular contractions and speed of stretch. Furthermore, the complexity of gymnastics events (four for females) requires not only different training approaches, but also a wide range of physical and physiological testing in order to monitor the progress of each gymnast (Monèm, 2011). Additionally, close monitoring of motor fitness should help gymnasts avoid injury and enhance performance by maximizing training

effects and avoiding overtraining (Sands, 2003). Although some tentative test batteries are available (Sleeper et al., 2012; USA-Gymnastics, 2014), most often they are local or try to identify a child with a specific motor profile or potential to do well in gymnastics (Albuquerque and Farinatti, 2007; Vandorpe et al., 2012). Moreover, it has been difficult to associate such results with competition marked on different apparatus or total scores (Bester and Coetzee, 2010; Claessens et al., 2006; Peeters and Claessens, 2013; Pool et al., 1969).

At present, no precise, agreed-upon definition of what constitutes an elite athlete is available. This is due in part to the diversity of sports' requirements (Coutinho et al., 2016), alongside ethnic and cultural specificities. Yet, studies conducted on elite gymnasts have somehow managed to provide their broad physical profiles. However, there is a lack of data that clearly show what differentiates between gymnasts considering different competitive/performance levels. The present review attempts to provide researchers and coaches with an overview of available data from the late 1960's to the present, identifying gymnasts' body size and shape and linking these characteristics to performance. Therefore, in this paper we aimed to provide: (i) a systematic review of the elite female gymnasts' physique, concentrating on their somatic features, somatotype, body composition, and biological maturation; and (ii) linkages between the physique and performance during competition. Specifically, this paper contributes to the literature by critically reviewing available reports that characterize the body physique of elite gymnasts, identifying possible gaps and hence, providing suggestions for future research. The first section reviews research "timelines" and the number and origin of the studies, and provides a general view of the available literature. The second section offers a summary of available data, with a critical analysis, as well as an identification of gaps that should be considered in future research..

Methods

An online search using Scopus, Web of Knowledge, Pubmed, Ebsco Sportdiscus, and B-On databases was conducted between November 2014 and May 2015. The following key words

were used to locate studies: artistic gymnastics, female, anthropometric characteristics, somatotype, maturation, body composition, and competitive performance, as well as their combinations. No specifically defined date was considered in our search. Inclusion criteria were as follows: (1) international academic texts investigating artistic gymnastics written in English, Portuguese and/or Spanish before May 2015, excluding literature reviews, interventions/training, and longitudinal studies about growth and maturation, gymnastics training loads, and nutritional disturbances; (2) having samples solely composed of elite female gymnasts, and (3) having anthropometry, somatotype, body composition and biological maturation related data. Additionally, the following screening steps were taken: (1) the article title and abstract were read to verify the inclusion criteria were met; (2) if so, then the full paper was read in its entirety to extract information on the country, author and publication year, sample size, measurement instruments, and main descriptive results. From a putative number of 407 papers, excluding duplication, following title and abstract screening, our search was narrowed down to 140 manuscripts. From these, 119 were excluded, and only 17 fulfilled all criteria and were retrieved as full-texts. These comprised only cross-sectional studies. The flowchart of the search process and item selection (Moher et al., 2009) is shown in Figure 1.

Results

In this paper results are presented in two steps. Firstly, we addressed the number of available papers as well as their publication years. Secondly, the main data were reviewed, i.e. body size and other body dimensions, somatotype, body composition and biological maturation.

Number and year of publications

Chronologically, the number of publications increased very little between 1969-1999 and 2000-2015; 7 publications were found between 1969-1999 and 10 between 2000-2015. In the first time period (1969-1999), studies reported data from Olympic, European and World Championships participants, mostly aiming to extensively characterize elite gymnasts (Claessens et al., 1990; Malina et al., 1984; Pool et al., 1969).

The appearance of Olga Korbut and Nadia Comaneci as prepubescent “little girls” (Ryan, 1995) marked the stage of very young girls attending the world podiums. This raised concerns about the sport impairing growth and delaying biological maturation, with a specific emphasis on eating disorders and injuries. During this period, age participation rules changed, increasing eligibility from 15 to 16 years of age for participants in World Championships and the Olympic Games, as a means to avoid prepubescent participation (Eagleman et al., 2014). During the second time period (2000-2015), apparently no new data about participants in world gymnastic competitions were published. Available papers continued the characterization of elite gymnasts from different countries, with a single study concerning participants in the 2002 European Championship. The remaining studies (Claessens et al., 2006; Peeters and Claessens, 2012; Peeters and Claessens, 2013) are based on the same data set previously collected in the 1987 World Championship. Only one article suggested changes in body size of American gymnasts (Sands et al., 2012).

Basic and extensive anthropometric data were reported in 17 articles; 10 had joint somatotype and anthropometry data. Body composition was presented in 7 articles, whilst biological maturation together with anthropometric data were considered only in 7 papers (Table 1). From the 17 papers, 8 originated from data collected during international competitions: 1 during the Olympic Games, 5 during World Championships and 2 from European Championships. Furthermore, information regarding performance in competition was only present in 5 reports.

Studies from the second analyzed period did not consider Olympic and/or world-class level gymnasts, and they consisted only of research from specific countries. Thus, we are in need of greater sample sizes of Olympic and world-class gymnasts to verify possible trends; furthermore, this novel data will provide new insights into elite gymnasts since the available data are outdated.

Body size and other body dimensions

As described by Malina et al. (2004), anthropometry refers to a set of standardized systematic measurement techniques of the body as a whole and of its parts. Body mass and height

are commonly used to express body size; thus, the reviewed research mostly reported body mass and height related data (Table 1); however, age differences and varied samples sizes limit a conclusive summary. This is because the final adult stature is required to make any definitive statements about potential growth reductions. What was found was that the smallest height values (144.7 ± 7 cm) were those of the youngest girls (12.6 ± 1.1 yrs), weighing 34.9 ± 5.5 kg (Theintz et al., 1989), while the tallest (163.2 ± 4.5 cm) were the older girls (16.8 ± 0.5 yrs), weighing 53.6 ± 3.1 kg (Malina et al., 1984). Across this spectrum, in comparison to reference standards, it was found that the smallest group was over one standard deviation below the 50th (z-value = -1.5) but still within the normal range for their chronological age. In contrast, the tallest group was one standard deviation above the 50th centile (z-value = 1.0) in comparison to girls of the same age based on WHO data reported by de Onis et al. (2007).

A decreasing age trend was observed between the 1967 European Championship (20.5 ± 2.0 yrs) and the 1987 World Championship (16.5 ± 1.8 yrs); this was accompanied by a decrease in competitors' average body height (158.4 ± 5.1 cm; 154.3 ± 6.5 cm) and mass (52.6 ± 4.8 kg; 45.5 ± 6.3 kg) (Claessens et al., 1990; Pool et al., 1969). A similar trend was observed in the American female team between 1956 and 1980, with an average stature decreasing from 161.8 ± 7.6 cm to 149.1 ± 4.3 cm and body mass from 55.6 ± 3.7 kg to 40.2 ± 3.9 . Although by 2008 American gymnast sizes had increased to 153.0 ± 7.0 cm and 47.5 ± 5.7 kg (Sands et al., 2012), it is clear that small bodies and lower body mass continued to be a characteristic demonstrated by elite gymnasts. This phenomenon has been verified worldwide in samples from Argentina, Italy and South Africa (Baleani et al., 2008; Bester and Coetzee, 2010; Massidda et al., 2013).

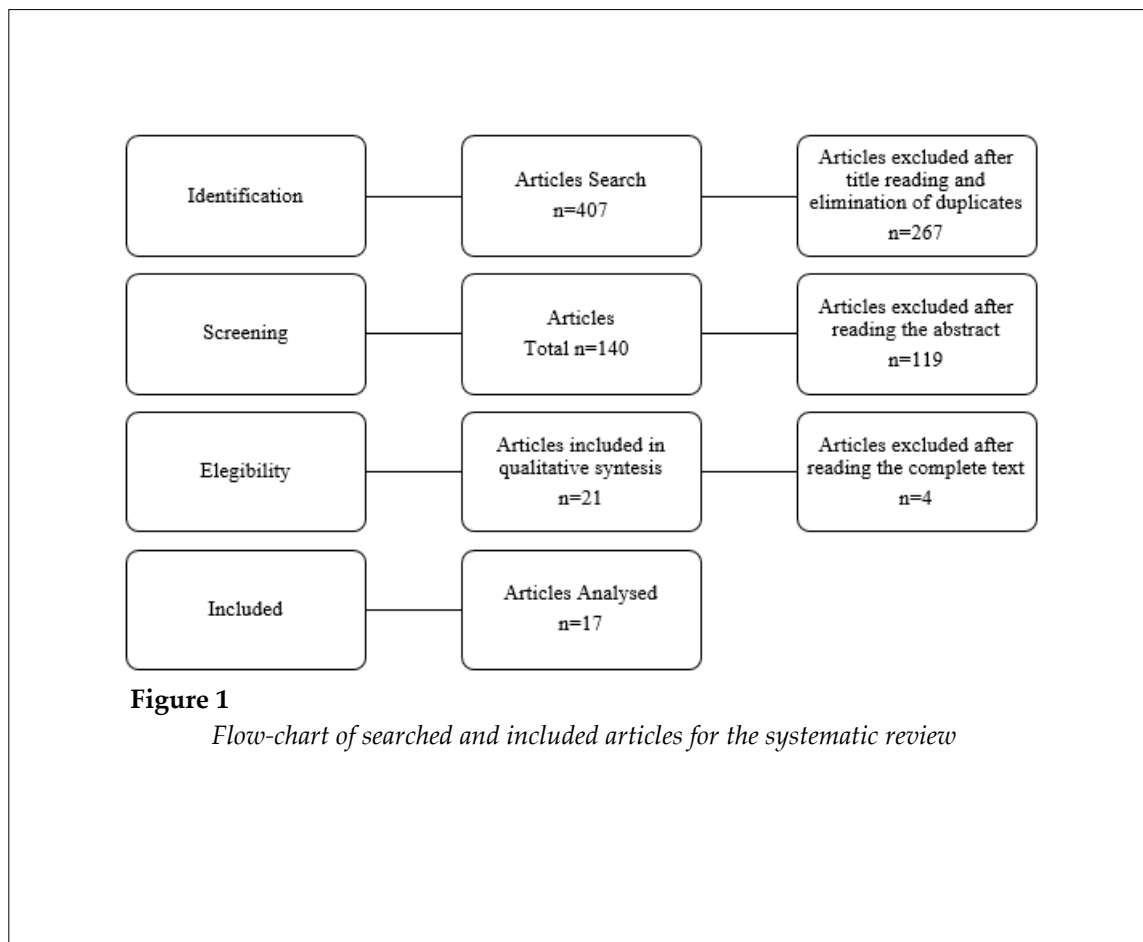


Table 1

Data origin included in this systematic review: sample size, age, anthropometry and body composition assessment methods

Study	Sample size	Sample origin	Age	Anthropometric measurements	Body composition
Pool et al. (1969)	38	European Championship Netherlands, 1967	20.5 ± 2 yrs	Height, Body mass, Sitting height, Leg length, Widths, Girths, Skinfolds	-
Thorland et al. (1981)	28	EUA	15.2 ± 1.5 yrs	Height, Body mass, Widths, Girths, Skinfolds	% Body Fat (indirect method based on underwater weighing)
Beunen et al. (1981)	23	Belgium	16.6 yrs (11.4 - 21.4 yrs.)	Height, Body mass, Sitting height, Leg length, Widths, Girths	-
Malina et al. (1984)	33	Olympic Game	14 - 17 yrs	Height, Body mass, Sitting height, Leg length, Widths, Skinfolds	-
Theintz et al. (1989)	34	Switzerland	12.6 ± 1.1 yrs	Height, Body mass, Sitting height, Span, Skinfolds	% Body Fat (double indirect method based on equation)
Claessens et al. (1990)	201	World Championship**	16.5 ± 1.8 yrs (13.2 - 23.8 yrs)	Height, Body mass, Sitting height, Lengths, Widths, Girths, Skinfolds	-
Claessens et al. (1991)	168	World Championship**	16.5 ± 1.8 yrs (13.2 - 23.8 yrs)	Height, Body mass, Sitting height, Lengths, Widths, Girths, Skinfolds	-
Deutz et al. (2000)	31	EUA	15.2 ± 1.8 yrs	Height, Body mass, BMI, Skinfolds	% Body Fat DEXA(a) and Skinfolds
Georgopoulos et al. (2004)	169	European Championship Greece, 2002	15.7 ± 2 yrs	Height, Body mass, BMI	% Body Fat (indirect method based on infrared data)
Claessens et al. (2006)	150	World Championship**	14 - 17.9 yrs	Height, Body mass, Sitting height, Leg length, Widths	-
Baleani et al. (2008)	11	Argentina	10 - 13 yrs	Height, Body mass, Sitting height, Leg length	Muscle Mass, Fat Mass (Method not reported)
Bester and Coetzee (2010)	12	South African	13.39 ± 2.14 yrs	Height, Body mass, Sitting height, span Widths, Girths, Lengths, Skinfolds	% Body Fat (double indirect method based on equation)
Sands et al. (2012)	106	EUA	15.7 ± 2.7 - 19.9 ± 2.4 yrs	Height, Body mass, BMI	-
Peeters and Claessens (2012)	129	Sub sample World Championship**	16.1 ± 1.2 yrs (13.2 - 18.5)	Height, Body mass, BMI Widths, Girths, Skinfolds	-
Peeters and Claessens (2013)	145	World Championship**	Age 16.4 ± 1.6 yrs (13.2 - 21.8)	Height, Body mass, BMI Widths, Girths, Skinfolds	-
Massidda et al. (2013)	42	Italians	13.4 ± 2.5 yrs	Height, Body mass, Widths, Girths, Skinfolds	-
João and Fernandes Filho (2015)	25	Brazilian	17.0 ± 4.7 yrs	Height, Body mass	% Body Fat, Muscle mass, Fat free mas (electrical bioimpedance)

**24th World Championships Netherlands-1987

(a) Dual-energy X-ray absorptiometry

Table 2

Study, sample size and origin, as well as age, somatotype and body composition data

Study	Sample Size	Sample Origin	Age	Somatotype	Body Composition
Thorland et al. (1981)	28	EUA	15.2 ± 1.5 yrs	2.3-5.0-3.2 SDI (c) = 3.02	Body fat 14.8 ± 4.1% underwater weighing
Beunen et al. (1981)	23	Belgium	16.6 yrs (11.4 - 21.4 years)	2.4-3.7- 3.1	
Theintz et al. (1989)	34	Switzerland	12.6 ± 1.1 yrs		Body fat 14.6 ± 3.2% Equation
Claessens et al. (1990)	201	World Championship**	16.5 ± 1.8 yrs (13.2 - 23.8 yrs)	LP (e) 2.1-3.5-3.3 MP (f) 1.6-3.4-3.3 HP (g) 1.3-4.0-3.3	
Claessens et al. (1991)	168	World Championship**	16.5 ± 1.8 yrs (13.2 - 23.8 yrs)	1.8-3.7-3.1	
Deutz et al. (2000)	31	EUA	15.2 ± 1.8 yrs		Body fat 12.3 ± 3.9% - DEXA(a) 11.3 ± 2.4% -Skinfold
Georgopoulos et al. (2004)	169	European Championship Greece, 2002	15.7 ± 2 yrs		Body fat 19.5 ± 4.2% Infrared
Baleani et al. (2008)	11	Argentina	10-13 yrs	10 years 3.1-3.7-2.5 11 years 2.1-3.3-2.3 12 years 2.7-3.8-2.7 13 years 2.4-3.2-2.6	Muscle mass(kg) Fat mass(kg) 10 yr 13.3 ± 3.2 5.7 ± 3.4 11 yr 15.8 ± 2.4 4.4 ± 0.6 12 yr 17.1 ± 5.1 4.9 ± 0.6 13 yr 17.4 ± 2.6 4.7 ± 0.6
Bester and Coetzee (2010)	12	South African	13.39 ± 2.14yrs	Successful 2.5-4.8- 2.8 Less success 2.2-3.6-3.6	Body fat -Equation Successful 15.9 ± 2.7% Less successful 14.8 ± 1.8%
Peeters and Claessens (2012)	129	Sub sample World Championship**	16.1 ± 1.2 yrs (13.2-18.5)	1.7-3.7-3.2	
Peeters and Claessens (2013)	145	World Championship**	Age 16.4 ± 1.6 yrs (13.2-21.8)	1.7-3.7-3.1 SAM (d) 1.0 ± 0.5	
Massidda et al. (2013)	42	Italians	13.4 ± 2.5 yrs	1.4-4.4-3.2 SAM (d) 1.0 ± 0.5	
João and Fernandes Filho (2015)	25	Brazil	17.0 ± 4.7 yrs	1.8-5.2-2.5	Body fat – BIA (b) 15.8 ± 3.8 Muscle mass (kg) 21.1 ± 3.4 Fat mass (kg) 7.5 ± 2.7 Fat free mass (kg) 38.1 ± 5.8

**24th World Championships Netherlands-1987

(a) Dual-energy X-ray absorptiometry; (b) electrical bioimpedance; (c) somatotype attitudinal distance; (d) somatotype attitudinal mean; (e) low performer; (f) middle performer; (g) higher performer.

Table 3

Study, sample size and origin, as well as age and biological maturity

Study	Sample Size	Sample Origin	Age	Biological Maturation
Beunen et al. (1981)	23	Belgium	16.6 yrs (11.4 - 21.4 years)	Skeletal age (TW2 Method) (a) Age at menarche 15.13 ± 1.7
Theintz et al. (1989)	34	Switzerland	12.6 ± 1.1 yrs	Skeletal age -Greulich-Pyle (yrs) 11.0 ± 1.3 RUS (yrs) 11.8 ± 1.4
Claessens et al. (1990)	201	World Championship**	16.5 ± 1.8 yrs (13.2- 23.8 yrs)	HP(d) Skeletal age RUS (yrs) 15.1 14.9 Age at menarche (yrs) 14.1 16.1
Claessens et al. (1991)	168	World Championship**	16.5 ± 1.8 yrs (13.2 - 23.8 yrs)	Age at menarche (yrs) 15.2 ± 1.4 (10.6-18.1) Skeletal age TW2 20 bone (yrs) 13.8 ± 0.8 RUS (yrs) 14.3 ± 0.9
Georgopoulos et al. (2004)	169	European Championship Greece, 2002	15.7 ± 2 yrs	Skeletal age Greulich-Pyle (yrs) 13.4 ± 1.8
Claessens et al. (2006)	150	World Championship**	14 to 17.9 yrs	Skeletal age TW2 Group 1 Group 2 Group 3 Age Group 14+ 14.0 ± 0.8 14.7 ± 0.2 - Age Group 15+ 14.2 ± 0.8 15.6 ± 0.3 - Age Group 16+ 14.4 ± 1.0 16.6 ± 0.3 - Age Group 17+ 14.3 ± 1.5 17.5 ± 0.3 -
Peeters and Claessens (2012)	129	sub sample World Championship**	16.1 ± 1.2 yrs (13.2-18.5)	Skeletal age TW2 14.5 ± 1.2

****24th World Championships Netherlands-1987**

(a) Tanner Whitehouse 2; (b) low performer; (c) middle performer; (d) higher performer.

It has been suggested that prerequisites for success in gymnastics depend, to some extent, on the athlete's physical characteristics, namely their somatic dimensions (Claessens et al., 1999). It is therefore not surprising that in 2004, Bradshaw and Le Rossignol (2004) reported that anthropometric measurements had traditionally

been used for the identification of talented gymnasts and that, in general, gymnasts had smaller both body height and mass than their chronologically age-matched peers. On average, when compared with normative age-related reference standards, the high-level gymnasts are characterized by a short stature and low body

mass (Claessens et al., 1999). Other anthropometric measurements have also been described, namely sitting height, widths, girths and some skinfolds (Bester and Coetzee, 2010; Beunen et al., 1981), showing very small variation across studies. Biacromial and biiliocrystal widths have also been measured as putative indicators of shape. What these studies have shown is that gymnasts in general have broad shoulders compared to small hip breadths, a rather remarkable feature of gymnasts (Claessens, 1999).

When elite gymnasts were compared across competitive levels, mostly considering the total score in competition, the highest ranked were found to be smaller and lighter (Claessens et al., 1990). Using the data from Claessens et al. (1990), Peeters and Claessens (2013) divided these gymnasts into three performance groups: lower (LP), middle (MP) and higher (HP) performers. This classification was based on their competitive performance (compulsory, free work and total score). It was found that members of the HP group were shorter, weighed less, and had a significantly smaller BMI than the LP group (151.6 cm, 41.3 kg, 18.1 kg·m⁻² compared to 158.4 cm 50.5 kg, 20.1 kg·m⁻², respectively). Pool et al. (1969) used a similar approach in assessing 38 elite female gymnasts, aged 20.5 ± 2 years, during the 1967 European championship, by collecting their competitive performance scores (total score in horse vault and floor exercises). They showed that the top ten tended to weigh less and had wider thorax width than their lower-rated competitive counterparts. Furthermore, they also found a negative correlation between subscapular skinfolds and competitive performance (-0.46, $p < 0.001$), although the correlation was positive with thorax width (0.40, $p < 0.01$).

At a national level, and contrary to previous findings, no statistically significant body height and mass mean differences were found between successful and less successful South African elite gymnasts (Bester and Coetzee, 2010), which was possibly a reflection of their low success in international competitions. These authors measured 61 anthropometric variables, but only 5 (mesomorphy and four girths: biceps, upper arm, wrist, and ankle) differed significantly between the groups (successful and less successful considering the vault score). Furthermore, performance in vault apparatus was investigated

with these variables as predictors in multiple regression models and biceps girth, size of the hand, and foot length accounted for 77.81% of the total variance. It is possible that these results are highly sample, country and apparatus specific because we were not able to find any other study that replicated these results.

In summary, being small and lightweight with slim hips relative to the shoulder width are likely to be part of the selection criteria used by coaches in the initial selection stages. These characteristics also appear to be linked to performance with respect to required apparatus skills' biomechanics (Borms and Caine, 2003). Furthermore, these characteristics might be associated with judging criteria (Claessens et al., 1999) and small size, for instance, is likely associated with higher marks.

Although the previous research mostly deals with so-called "elite" gymnasts, no clear-cut definition of what exactly is an elite gymnast has been provided. Furthermore, a more precise definition of a competitive level is needed, since different criteria most probably bias the interpretation of the available information. Future research could concentrate on changes in body size and, if longitudinal data are available, on gymnasts of different competitive levels.

Somatotype

Another area of research involves the gymnasts' body type, i.e., their somatotype, given that it plays a key role in artistic gymnastics evaluation, which is also influenced by aesthetic aspects. Very briefly, the somatotype is defined as the quantification of the body shape and composition irrespective of size, and is represented by three components: endomorphy (expressing relative fatness), mesomorphy (relative musculo-skeletal robustness) and ectomorphy (relative linearity or slenderness) of a physique (Carter and Heath, 1990). Although differences were found in mean somatotype components across studies (Table 2), mesomorphy was systematically reported as the most important physique component, and elite female gymnasts are broadly classified as ecto-mesomorph. The highest mesomorphy value (5.2) was described in Brazilian gymnasts aged 17.0 ± 4.7 yrs (Ferreira João and Fernandes Filho, 2015) and the smallest (3.2) in Argentinians aged 13 yrs (Baleani et al., 2008). For endomorphy, the highest value (3.1)

was described in 10 yrs old Argentinians (Baleani et al., 2008) and the smallest (1.3) in the best ranked gymnasts (17.6 yrs) participating in the 1987 World Championships (Claessens et al., 1990). In terms of ectomorphy, the highest value (3.6) was found in less successful South Africans aged 13.39 ± 2.14 yrs (Bester and Coetzee, 2010) and the smallest (2.3) found in 11 yrs old Argentinians (Baleani et al., 2008).

In general, there seems to be a slight increasing trend towards mesomorphy with a corresponding decrease in endomorphy, with the exception of American junior gymnasts (Thorland et al., 1981). No information was available for either European or Olympic gymnasts. In non-athlete girls, endomorphy tends to increase with age, especially during adolescence; ectomorphy also increases with age until peak height velocity (around 12 years old), then tends to decline. Their somatotype is moderately stable during pre-adolescence, but changes during adolescence are associated with differences in growth timing and tempo as well as sexual maturation (Malina et al., 2004).

When studying contrasting groups, elite gymnasts showed significant differences compared to control groups, even after making adjustment for skeletal age. For example, gymnasts (1.7-3.7-3.2) were lower in endomorphy and higher in ectomorphy than a control group (4.0-3.0-2.9) (Peeters and Claessens, 2012). Similarly, Thorland et al. (1981) suggested that particular features of gymnasts' body composition and body physique tended also to typify their proficiency. For example, a somatotype is a good discriminating factor between successful and less successful gymnasts (Bester and Coetzee, 2010). Additionally, when somatotype components were compared with final scores (competition performance) in three distinct groups of lowest (LP), middle (MP) and highest levels (HP), mesomorphy (3.8, 3.8, 3.7) was not a differentiating element, although endomorphy was lowest in HP (1.2) when compared to other groups with 2.4 and 2.1, and ectomorphy was higher in HP when compared with LP and MP groups, with their means equal to 2.9 (LP), 2.8 (MP) and 3.5 (HP) (Peeters and Claessens, 2013).

In summary, although differences were found in mean somatotype components across samples over the years, gymnasts were

characterized as ecto-mesomorph, which is a favorable physique in biomechanical terms to excel in performance (Borms and Caine, 2003). Aesthetic physiques with a preponderance of linearity and mesomorphy seem to be expected by judges, i.e., an existing stereotype that may influence judges' perceptions (Claessens et al., 1999).

Body composition

There is no doubt that success in gymnastics is also associated with comparatively low levels of body fat, especially in elite ranks of training and competition (Borms and Caine, 2003). Although body composition data are available, it is difficult to compare them because of the diversity of approaches used in each paper - underwater weighing, DEXA, skinfolds, near-infrared interactance, and electrical bio impedance (Table 1). The oldest study reviewed (Thorland et al., 1981) used underwater weighing, while more recent ones relied mostly on anthropometry (Baleani et al., 2008; Bester and Coetzee, 2010; Deutz et al., 2000; Theintz et al., 1989), near-infrared interactance (Georgopoulos et al., 2004) and bioelectrical impedance (Ferreira João and Fernandes Filho, 2015). These reliable and inexpensive methods are very easy to implement, do not cause too many assessment problems, and the information is readily available to gymnasts and coaches (Nana et al., 2015). However, they are still prone to prediction errors and must be used with care (Moon, 2013).

Most research (Table 2) presents relative fat mass (fat percentage); only two studies provided absolute values of muscle mass, fat mass and fat-free mass (Baleani et al., 2008; Ferreira João and Fernandes Filho, 2015). The smallest % of body fat values were $11.3 \pm 2.4\%$ (skinfolds) and $12.3 \pm 3.9\%$ (DEXA) obtained in the same sample aged 15.2 ± 1.8 yrs (Deutz et al., 2000). On the other hand, the highest value was $19.5 \pm 4.2\%$ (near-infrared interactance) in 15.7 ± 2 yrs olds (Georgopoulos et al., 2004). Although difficult to compare, these results are apparently within the range suggested by Wilmore (1983), from 9.6 to 23.8%, in gymnasts whose heights varied from 158 to 63 cm, body mass from 51.5 to 57.9 kg and were aged between 14 and 23 years old.

It has become evident that female gymnasts have a very low % body fat when compared to chronologically age-matched non-

gymnast groups (Cassell et al., 1996; Soric et al., 2008), although caution in interpretation is necessary since their biological age is also lower. On the other hand, when comparisons between competition levels were performed, no significant differences were found between successful ($15.9 \pm 2.7\%$) and less successful gymnasts ($14.8 \pm 1.8\%$) as shown by Bester and Coetzee (2010). Additionally, when world-level gymnasts were divided according to their final scores (competition performance) in three distinct groups of lowest (LP), middle (MP) and highest levels (HP), those belonging to the HP group had significantly lesser % fat mass than the LP group (Claessens et al., 1990).

In summary, gymnasts have a low % body fat for CA. Yet, notwithstanding its importance in athletic performance, gymnasts' body composition is also considered an aesthetic issue that is certainly linked to pressure to display a characteristic appearance to probably impress jury members (Borms and Caine, 2003).

Biological Maturation

The last topic of our review is related to biological maturation, an issue frequently mentioned in the available reports on female athletes, although it is sometimes forgotten when discussing gymnasts' selection. Biological maturation refers to the progress towards a biologically mature state. The process of maturing consists of two components, timing and tempo. Timing refers to when specific maturational events occur, while tempo relates to the rate at which maturation progresses, and both vary considerably among individuals. Biological maturation is most often viewed in the context of skeletal (skeletal age), sexual (secondary sex characteristics) and somatic (age at peak height velocity) maturation (Baxter-Jones et al., 2002). In the available gymnasts' data (Table 3), biological maturation was mostly described by skeletal age (Greulich-Pyle and Tanner-Whitehouse II methods); age at menarche and corresponding menarcheal statuses are also reported. The majority of the literature indicates that elite female gymnasts are likely to be late-maturing. For example, when using skeletal age assessed with the Tanner-Whitehouse II (TW2) method, gymnasts participating in the 1987 World Championship had a significantly lower mean skeletal age compared to sedentary age-matched

reference norms (14.5 ± 1.2 and 15.2 ± 1.1 , respectively) (Peeters and Claessens, 2012).

Although not all gymnasts are late in their maturity, a difference of 2.5-3.0 yrs has been found between chronological (CA) and skeletal age (SA) (Beunen et al., 1981). Similarly, Theintz et al. (1989) described a mean difference of 1.6 and 0.8 yrs. between CA and SA, both of them with specific samples from Belgium and Switzerland, respectively. Likewise, Claessens et al. (1991) also found a difference of 2.7 yrs between CA and SA in a world level sample (1987 World Championship). Almost 13 years later, Georgopoulos (2004) revealed that in gymnasts participating in the 24th European Championship held in Greece in 2002, the difference between CA and SA was 2.3 yrs.

Age at menarche in Belgian gymnasts (Beunen et al., 1981) was reported to be at 15.13 ± 1.7 yrs. A similar value, 15.2 ± 1.4 yrs, was also found in a world-level sample participating in the 1987 World Championship (Claessens et al., 1991). Both these values show the age at menarche occurring later when contrasted with age-matched controls. Furthermore, when comparing gymnasts from different competitive levels, pre-menarcheal gymnasts tend to have higher competitive scores (72.5, 73.4, 73.5), on average, than post-menarcheal gymnasts (70.3, 70.8, 72.3) at the same chronological age (14+, 15+, 16+ yrs) (Claessens et al., 2006).

In summary, later age in maturity markers, skeletal age and age at menarche, are consistent characteristics displayed by elite gymnasts, regardless of the origin of the sample, i.e., local gymnasts or world-class. Late-maturing gymnasts seem to have advantages in motor performance, training and competition (Baxter-Jones and Helms, 1996). However, there is limited evidence that late maturation is caused by gymnastics training (Malina et al., 2013).

Conclusions

In conclusion, based on our review, although the physique of gymnasts is well described, less is known about the differentiation of physiques between competitive levels. The physique of the elite gymnast is characterized by small size and low body mass, with a predominance of ecto-mesomorphy, low fat mass and late maturity. However, a general consensus

is still lacking on whether these features explain competitive performance or even differentiate gymnasts within distinct competitive levels. Furthermore, given the apparent systematic selection processes, transformations in their training schedules, long-term preparation, as well as changing competition rules across the years, available data are still deficient in providing robust conclusions concerning alterations in their physical structure, i.e. today's elite gymnasts' multivariate profiles. This could help coaches to easily access reliable and valid data summaries which may also reflect important aspects of their

training processes. It is also important to consider the possibility of enlarging sample sizes to ensure greater generalizability. In addition, researchers do not consistently compare gymnasts from different competitive levels, such as elite and non-elite, probably because of the difficulty to define or categorize these two groups. Finally, studies with Olympic and world-class gymnasts will provide new information about gymnasts, since available data are outdated. Judges' perceptions about gymnast's body size and shape should also be systematically addressed.

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