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Height Velocity and Skeletal Maturation in Elite Female Rhythmic Gymnasts

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Rhythmic gymnasts performing under conditions of high intensity are exposed to particularly high levels of psychological stress and intense physical training, factors that can contribute to the observed delay in skeletal maturation and pubertal development, and alter optimal growth.

The study was conducted in the field, during the International, European, and World Rhythmic Sports Gymnastics Championships of the years 1997–2000, and included 104 elite female rhythmic gymnasts, aged 12–23 yr. The study included height and weight measurements, estimation of body fat and skeletal maturation, and registration of parental height. Height, weight, target height, and predicted adult height were expressed as the SD score of the mean height and weight for age, according to Tanner's standards.

Gymnasts were taller and thinner than average for age, with height velocity SD score for each age group above the 50th percentile for all age groups (n = 140, mean = 1.9 ± 2.5). Interestingly, although height velocity in normal girls comes to an end by the age of 15, in our examined rhythmic gymnasts it continues up to the age of 18.

There was a delay of skeletal maturation of 1.8 yr (n = 72, r = 0.730, *P* < 0.001), compensated by an acceleration of height velocity toward the end of puberty.

The final adult height was identical to the estimated predicted height at first evaluation, and significantly higher than the genetically determined target height (n = 35, r = 0.58, *P* < 0.001), denoting that genetic predisposition to final height is not only achieved, but even exceeded.

Using multiple regression analysis, target height was the only independent parameter that has been proven to influence positively the height velocity SD score (b = 0.233, t = 2.215, *P* = 0.029), denoting that genetic predisposition remains the main driving force for the observed efficient catch up growth.

In conclusion, the elite rhythmic gymnasts compensate for their loss of pubertal growth spurt by a late acceleration of linear growth. Despite the delay in skeletal maturation, genetic predisposition of growth is not only preserved, but even exceeded. (*J Clin Endocrinol Metab* 86: 5159–5164, 2001)

GENETIC PREDISPOSITION TO growth can be fully expressed only under favorable environmental conditions (1). Rhythmic gymnasts performing under conditions of high intensity are exposed to particularly high levels of psychological stress and intense physical training. The deleterious effects of these factors upon growth, skeletal maturation, and pubertal development have been documented in a variety of sports, including artistic gymnasts (2–6).

In artistic gymnasts, conflicting results have been reported in the literature. Cross-sectional studies did not reveal a negative effect on final height (7–12). However, in a prospective study by the same investigators, a decrease in mean height predictions with time has been observed which could finally diminish adult height (13). It is to be noted that rhythmic and artistic gymnastics are two distinct sports within the area of gymnastics. Their program includes specific gymnastics and requires specific and different skills.

We reported that psychological stress and physical training have profound effects on growth and pubertal development of elite female rhythmic gymnasts (14). Despite the observed significant delay in skeletal maturation and pubertal development, genetic predisposition to growth was maintained and adult final height was not expected to be affected. Due to the inherent inaccuracy of height predictions, a prospective study was initiated to evaluate longitudinally the pattern of growth throughout puberty in elite female rhythmic gymnasts. The aim of this study was to obtain information of height velocity progression in parallel to skeletal maturation. This study is unique in character, as all variables were measured on the field of competition.

Abbreviations: TH, Target height.

Subjects and Methods

The data were obtained during the International, European, and World Rhythmic Sports Gymnastics Championships of the years 1997–2000, in Patras, Greece; Sevilla, Spain; Kalamata, Greece; and Osaka, Japan. The study was conducted under the authority of the Federation Internationale de Gymnastique and the European Union of Gymnastics, according to article 7 of the medical authority in the official Federation Internationale de Gymnastique competition guidelines. All athletes participated voluntarily under the authorization of the heads of their national delegations, and they were free to deny participation in any particular component of the procedure. The study included 104 elite rhythmic gymnasts aged 12–23 yr, which have been evaluated twice within an interval of 1 yr (±3 months). Eighteen of these athletes have been reevaluated yearly for a period of 2 yr, and 9 athletes have been reevaluated yearly for a period of 3 yr. Athletes were of different ethnic origin from 28 different countries. A few individual gymnasts and delegates from few countries refused to authorize participation of their athletes due to personal reasons or because they had been recently submitted to medical examinations.

Data collection

The study protocol included noninvasive clinical and laboratory investigations as well as the completion of a questionnaire. The clinical evaluation included height and weight measurements and assessment of breast and pubic hair development. The same physician measured both weight and height. Weight was assessed with a calibrated balance-beam scale, and height was assessed with a Martin-type anthropometer. Height was recorded as the mean of two consecutive measurements. Breast and pubic hair development were assessed by a female physician (A.T.) according to Tanner's stages of pubertal development (15).

The laboratory investigation included determination of skeletal maturation and body composition. Skeletal maturation was evaluated from an x-ray of the left hand and wrist, executed in a separate room under full body protection against radioactivity. All radiographs were evaluated blindly by two physicians, and bone age was determined according to Greulich-Pyle standards. Near total skeletal maturation was considered when bone age was greater than 16 yr of age. Prediction of adult height was calculated according to Bayley-Pinneau method, based on measured height and bone age, as assessed using the Greulich-Pyle standards (16). For those athletes whose radiographs showed near total skeletal maturation (bone age > 16 yr), and for those athletes over 18 yr of age, without bone age estimation, whose two consecutive height measurements were equal, the measured actual height was considered to be the adult height (n = 35).

It is to be noted that Greulich-Pyle and Bayley-Pinneau standards are developed for North American children. As normative data on skeletal maturation for each different ethnic group are not available, these standards should be used with caution in any multiethnic study.

Body composition was determined by a portable apparatus (Futrex 500, Futrex, Inc., Gaithersburg, MD), which estimates percent body fat and total body water based on infrared analysis (14). This technique uses the principles of light absorption and reflection to convert electromagnetic radiation, transmitted and reflected through subject's biceps, to OD measurements used to calculate percent body fat and total body water (17).

The accuracy and precision of the near infrared analysis has been validated to be equivalent to the standard methods of body composition assessment by skinfold measurements (18) and bioimpedance assessments (19).

All athletes completed a questionnaire including personal (onset and intensity of training, number of competitions per year) and family data (paternal and maternal heights).

The reported target height (TH) was estimated using the midparental height as an index of genetic predisposition to adult height. The equation TH = (father's height −13 + mother's height)/2 was used for determining TH (20).

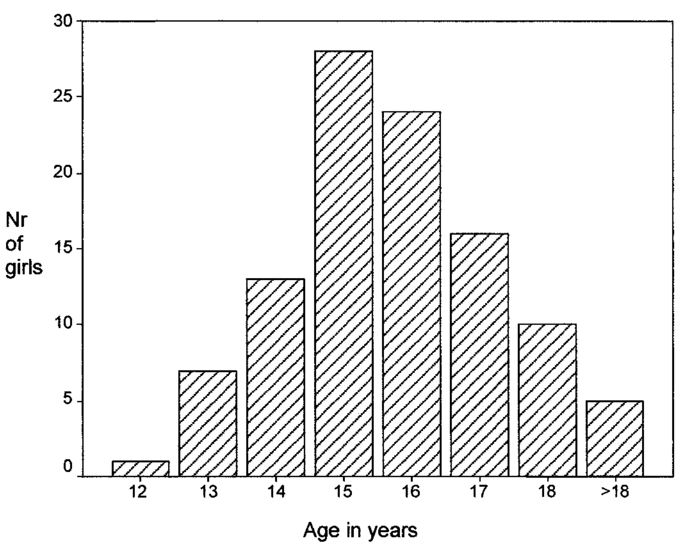

FIG. 1. Distribution according to chronological age.

Statistical analysis

For statistical evaluation, height and weight were expressed as the SD score of the mean height and weight for age, according to Tanner's standards (21). The SD score was also calculated for reported TH and predicted adult height. The Pearson product moment correlation coefficient, with two-tailed test of significance, was used to assess all studied relationships. A multiple regression analysis (ANOVA) was used to ascertain the independent predictive value of each studied parameter.

Correlations with a critical value of $P < 0.05$ were considered significant.

TABLE 1. Collected and derived data of all examined rhythmic gymnasts at first examination

Collected data (n = 104)		
Variable	Mean	SD
Age (yr)	16.0	1.7
Height (cm)	163.6	5.6
Target height (cm)	165.4	4.6
Weight (kg)	45.3	6.6
BMI (kg/m^2)	16.8	1.8
Body fat (%)	15.9	4.9
Onset of training (yr)	7.3	2.3
Number of competitions	6.4	2.7
Intensity of training (h/w)	32.5	13.5
Derived data (n = 104)		
Variable	Mean	SD
Height SD score	0.3	0.9
Weight SD score	−1.0	0.5
Target height SD score	0.5	0.7
Height velocity (cm/yr), n = 140	2.4	1.7
Height velocity SD score, n = 140	1.9	2.5

TABLE 2. Collected and derived data of examined rhythmic gymnasts with bone age estimation, at first examination (n = 72)

Variable	Mean	SD
Age (yr)	16.2	1.8
Bone age (yr)	14.0	1.8
Height SD score for chronological age	0.4	0.9
Height SD score for bone age	1.1	1.1
Height velocity (cm/yr)	2.2	1.8
Height velocity SD score	1.5	2.7
Target height (cm)	166.5	3.9
Target height SD score	0.7	0.6
Predicted height (cm)	168.6	4.6
Predicted ht SD score	1.1	0.8
Predicted minus target ht SD score	0.4	0.9
Weight SD score	−1.1	0.6

TABLE 3. Collected and derived data of all rhythmic gymnasts who had reached adult height (n = 35)

Variable	Mean	SD
Age (yr)	18.0	1.7
Adult height (cm)	169.0	5.1
Derived data		
Adult height SD score	1.1	0.8
Target height (cm)	167.4	4.4
Target height SD score	0.8	0.7
Adult minus target height SD score	0.3	0.7
Predicted height at start (cm)	168.9	5.1
Predicted height SD score at start	1.1	0.9

All statistics were performed using SPSS, Inc. (Chicago, IL) for windows, version 9.0.1 (Feb. 24, 1999).

Results

The age distribution of examined gymnasts ranged from 12–23 yr. The higher incidence was between 15–17 yr, with a peak at the age of 16 yr (Fig. 1).

Anthropometric characteristics

The mean values and SD scores for collected and derived data of all examined gymnasts are shown in Table 1. These data are collected during their first clinical evaluation. For those athletes who were reevaluated more than twice over a period extending 2 yr (±3 months), height velocity and height velocity SD score were calculated yearly (Table 1, derived data, n = 140). The mean values and SD scores for predicted adult height and for the difference between predicted adult height and TH, derived from those gymnasts who had at least one annual reevaluation of their bone age (n = 72) are presented in Table 2. For this subgroup of rhythmic gymnasts, height SD score and height velocity SD score were calculated for chronological age and bone age (see Table 2). There was a delay in skeletal maturation, compared with chronological age, of 1.8 yr, which was statistically significant (r = 0.730, $P < 0.001$).

For those athletes who reached their final adult height (n = 35), the mean values and SD scores for adult height and for the difference between adult height SD score and reported TH SD score are shown in Table 3. It is to be noted that their adult height is identical to their estimated predicted height at their first evaluation and significantly higher than their genetically determined TH (r = 0.58, $P < 0.001$).

The height SD score and weight SD score for each age group from 12 to over 18 yr of age are shown in Fig. 2. Rhythmic gymnasts were taller than average height for age, with mean heights above the 50^{th} percentile for all age groups. However, rhythmic gymnasts were lighter than average, with mean weight for age well below the 50^{th} percentile.

The height velocity SD score for each age group was above the 50^{th} percentile for all age groups. The highest values were recorded between years 14–16 (2.8 ± 2.2 at 14, 2.6 ± 2.5 at 15, and 3.0 ± 2.6 at 16 yr of age). It is to be noted that height velocity remains well over the mean values for age for all age groups, with a peak at the age of 16. The height velocity mean values per chronological age are presented in Fig. 3. It is of particular interest that, although height velocity in normal girls comes to an end by the age of 15, in our examined rhythmic gymnasts it continues up to the age of 18.

Relationships

To evaluate associations between the SD scores of height and genetic, metabolic, and sport-related factors that could influence growth, correlation coefficients were calculated be-

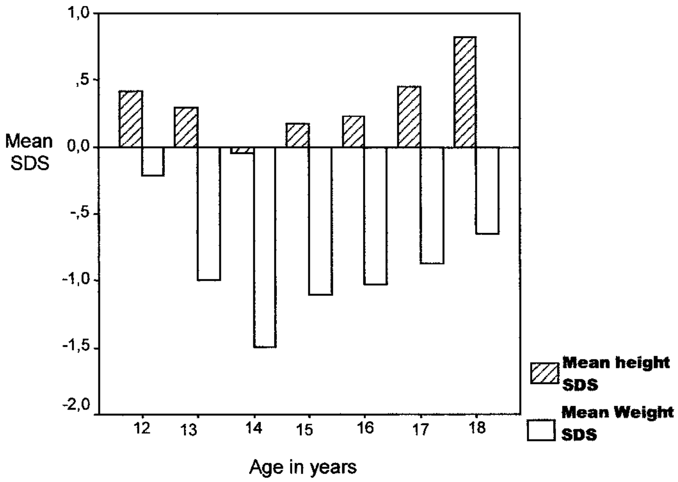

FIG. 2. Height and weight SD score (SDS) for chronological age.

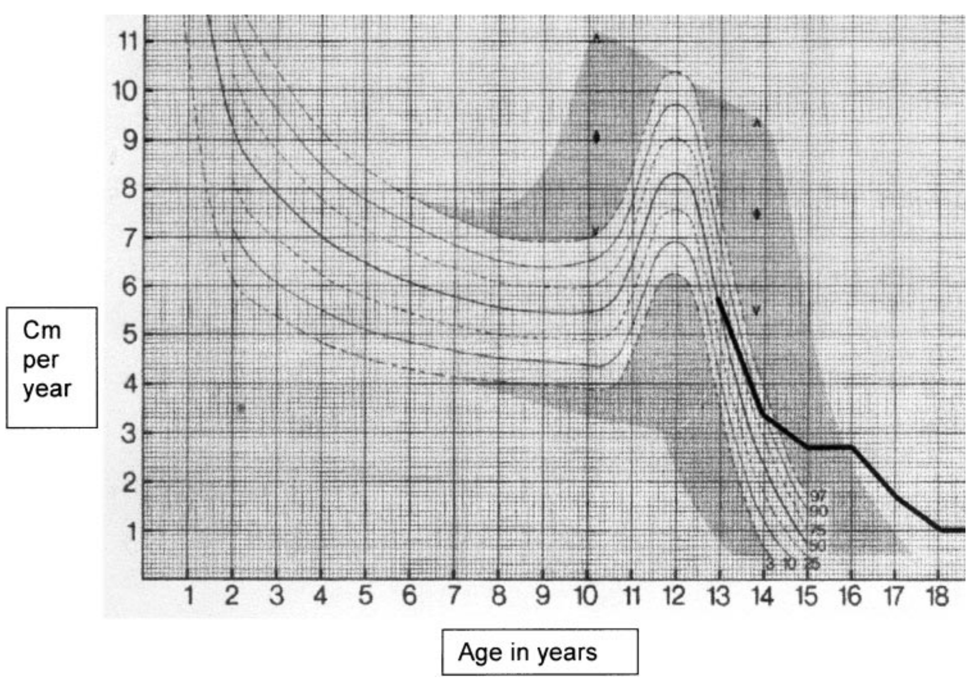

FIG. 3. Height velocity mean values per chronological age. Lines represent the 3^{rd}, 10^{th}, 25^{th} 50^{th}, $75^{th,}$ 90^{th}, and 97^{th} percentiles of height velocity. The *dark line* represent the height velocity of our examined gymnasts. The *dark gray area* includes the velocity curves of all children who have their peak velocities up to two standard deviations of age before and after this average age. The *arrows* and *diamonds* mark the 3^{rd}, 50^{th}, and 97^{th} percentiles of peak velocity when the peak takes place at these early and late limits (Ref. 21).

tween height SD score, height velocity SD score, and TH SD score, body mass index (BMI), percent body fat, onset of training, number of competitions per year, and intensity of training (Table 4).

The actual height SD score was positively correlated to TH SD score ($P = 0.02$), to weight SD score ($P < 0.001$), and to number of competitions per year ($P < 0.001$). The height velocity SD score was positively correlated to TH SD score ($P = 0.01$), and negatively to weight SD score ($P < 0.001$), and to BMI ($P < 0.001$).

A multiple regression analysis was used to ascertain which of the above parameters had independent value in predicting height SD score and height velocity SD score (see Table 5). The actual height SD score was independently influenced positively by weight SD score (b = 1.228, t = 13.51, $P < 0.001$), and no. of competitions (b = 0.139, t = 2.40, $P = 0.018$) and negatively by BMI (b = −0.646, t = −6.24, $P < 0.001$), and body fat (b = −0.21, t = −3.00, $P = 0.003$). The height velocity SD score was independently influenced positively by TH SD score (b = 0.233, t = 2.215, $P = 0.029$) and negatively by weight SD score (b = −0.417, t = −2.617, $P = 0.010$).

For those athletes who had been reevaluated yearly for bone age estimation, correlation coefficients were calculated between predicted height SD score and TH SD score, difference between predicted height SD score and TH SD score, height velocity SD score, and weight SD score (Table 6).

The predicted height SD score was positively correlated to the difference between chronological age and bone age ($P = 0.05$), to TH SD score ($P = 0.03$), to weight SD score ($P = 0.02$), and to the difference between predicted height SD score minus TH SD score ($P < 0.001$).

Discussion

Elite female rhythmic gymnasts exhibit a specific pattern of growth characterized by a marked delay in skeletal maturation (14). There is general agreement that the same characteristics are also noted among artistic gymnasts (6–12). In a previous cross-sectional study, we have shown that, despite the delay in skeletal maturation and in pubertal development, genetic predisposition was preserved and adult final height was expected not to be affected (14). In a series of previous studies in artistic gymnasts (12, 13, 22), cross-sectional height predictions of final height were not reduced (12, 22), but in a prospective study by the same investigators, a reduction of growth potential and a decrease of height predictions with time was noted (13). To our knowledge, there is no information in the literature referring to the progression of growth in rhythmic gymnasts.

These data provide evidence that the delay in skeletal maturation and pubertal development observed in female rhythmic gymnasts is compensated by an acceleration of height velocity toward the end of puberty. Human growth is a regular process characterized by a pattern of changing height velocity from childhood to adulthood (15). Normal puberty starts with a period of increased height velocity, reaches a peak, and afterwards gradually decreases until growth ceases at the end of puberty. The elite rhythmic gymnasts compensate their attenuation of pubertal growth spurt due to pubertal delay, by a late acceleration of linear growth. Catch-up growth is defined as a height velocity above the statistical limits of normalcy for age and/or maturity during a defined period of time, following a transient period of growth inhibition (23, 24). If a

TABLE 6. Predicted height SD score of examined rhythmic gymnasts with bone age estimation: correlation coefficients

Variable	Predicted height SD score
Δ age-bone age	n = 71, r = 0.23, $P = 0.05$
Height velocity SD score	n = 69, r = −0.24, $P = 0.84$
TH SD score	n = 61, r = 0.29, $P = 0.03$
Weight SD score	n = 64, r = 0.29, $P = 0.02$
BMI	n = 71, r = −0.05, $P = 0.97$
Body fat	n = 70, r = −0.01, $P = 0.95$
Predicted minus target height SD score	n = 62, r = 0.62, $P < 0.001$

TABLE 4. Actual height and height velocity SD score for all examined rhythmic gymnasts: correlation coefficients

Variable	Height SD score	Height velocity SD score
TH SD score	n = 117, r = 0.28, $P = 0.02$	n = 124, r = 0.22, $P = 0.01$
Weight SD score	n = 128, r = 0.64, $P < 0.001$	n = 130, r = −0.35, $P < 0.001$
BMI	n = 131, r = 0.24, $P = 0.06$	n = 138, r = −0.30, $P < 0.001$
Body fat	n = 128, r = −0.14, $P = 0.10$	n = 135, r = −0.16, $P = 0.06$
Onset of training	n = 111, r = −0.03, $P = 0.72$	n = 114, r = 0.14, $P = 0.13$
No. of competitions	n = 107, r = 0.34, $P < 0.001$	n = 117, r = 0.03, $P = 0.78$
Intensity of training	n = 108, r = −0.05, $P = 0.64$	n = 115, r = −0.06, $P = 0.50$

TABLE 5. Actual height and height velocity SD score for all examined rhythmic gymnasts: multiple regression analysis (ANOVA)

Variable	Height SD score[a]	Height velocity SD score[b]
TH SD score	b = 0.068, t = 1.166, $P = 0.247$	b = 0.233, t = 2.215, $P = 0.029$
Weight SD score	b = 1.228, t = 13.51, $P < 0.001$	b = −0.417, t = −2.617, $P = 0.010$
BMI	b = −0.646, t = −6.24, $P < 0.001$	b = 0.137, t = 0.747, $P = 0.457$
Body fat	b = −0.21, t = −3.00, $P = 0.003$	b = −0.122, t = −0.95, $P = 0.344$
Onset of training	b = −0.052, t = −0.97, $P = 0.334$	b = 0.10, t = 1.132, $P = 0.261$
No. of competitions	b = 0.139, t = 2.40, $P = 0.018$	b = −0.007, t = 0.064, $P = 0.949$
Intensity of training	b = 0.028, t = 0.48, $P = 0.627$	b = −0.193, t = −1.84, $P = 0.069$

[a] Adjusted $R^2 = 0.752$, DF = 7, F = 41.8, $P = 0.000$.
[b] Adjusted $R^2 = 0.161$, DF = 7, F = 3.637, $P = 0.002$.

child or adolescent with growth retardation simply returns to a normal height velocity, catch-up growth does not occur (23). Indeed, our examined rhythmic gymnasts present an above average for age height velocity, starting from the age of 14 yr, reaching a peak at the age of 16, and exceeding the age of 18, when in normal growing adolescents, linear growth is expected to be terminated. The ultimate success of catch-up growth largely depends upon the time of onset, the duration, and the speed of progression. It is difficult, therefore, to predict catch-up growth from an early stage (24). Our data clearly demonstrate that in elite female rhythmic gymnasts, catch-up growth is a late and slow process, and because it is coupled with delayed puberty, there is sufficient time for optimal skeletal maturation. In contrast, catch-up growth coinciding with pubertal growth spurt, would end up in a significantly decreased final height, due to rapid bone maturation (24). It should be noted that in our study, predicted adult height is higher than TH. In addition, actual height, predicted adult height, and height velocity all positively correlate with TH, which means that genetic predisposition is not disrupted. All sports-related parameters such as low body weight and low body fat independently contribute to the delay in skeletal maturation and pubertal progression. It is of particular importance that TH is the only independent parameter that has been proven to influence positively the height velocity SD score. Genetic predisposition remains the main driving force for this efficient catch-up growth that compensates for and even exceeds the previous period of growth inhibition.

Height predictions, irrespective of the methods used for their estimation, have been criticized for their inherent inaccuracy. Although definite conclusions should not be made unless adult height will be attained, in the vast majority of examined athletes, the finding of an almost identical adult height to the initially predicted adult height in those athletes who fulfilled their skeletal development, argue against an overestimation of our predictions of adult height. Nevertheless, the positive difference between adult height SD score and TH SD score, demonstrates that genetic predisposition to final height is not only achieved, but even exceeded. This may be due to the positive change of socioeconomic conditions between the present and the past generation and to the stimulating influence of exercise on growth as pointed out by the finding of a positive correlation between actual height and the number of athletic competitions per year. Delayed pubertal development and delayed menarche provide evidence of low oestrogenic effect on bone maturation during late puberty, allowing additional time for growth (14). On the other hand, psychological stress, intensive physical training, and inadequate energy intake relative to energy output, are well known factors that can impair optimal growth (25–28). The nutritional deficit has been proven to independently influence negatively the actual height (low body weight and low body fat) and should be considered as the main cause for the observed delay in skeletal maturation and pubertal progression. Although a certain somatometric phenotype (taller and thinner than average) is related to success in performance (29), our positive correlation between actual height, predicted height and weight, denotes the careful monitoring of energy balance and adequate nutritional intake in which the studied gymnasts were subjected by their trainers. In conclusion, the findings of our study demonstrate the profound effects of stress and intense physical activity on growth and skeletal maturation of elite female rhythmic gymnasts. The elite rhythmic gymnasts compensate their loss of pubertal growth spurt, by a late acceleration of linear growth. Despite the delay in skeletal maturation, genetic predisposition of growth is not only preserved, but even exceeded.

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