COMPARISON OF ACTUAL AND PREDICTED ANTHROPOMETRIC CHARACTERISTICS OF CZECH ELITE GYMNASTS

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Abstract

In context of artistic gymnastics, the influence of intense training on the growth and development of male and female gymnasts is often discussed. The aim of this work is to compare the attained and predicted body height and length of body segments in 11 elite male gymnasts from the Czech Republic who have undergone intense trainings for 12 years or more. The average age of the research sample was 33 ± 11.5 years, body height 174.9 ± 4.1 cm and weight 71.5 ± 5.13 kg. Using standardized anthropometric measurements, we obtained the body height (BH) and length of the trunk, upper and lower limbs, arms, forearms, thighs, and calves. Using the t-test (p .05) <, a comparison of the actual and predicted body height was made using three different predictive equations. The results were also compared with relative lengths of body segments as reported by Chaffin & Andersson and Brugsch. In most cases, the results indicated lower actual body height than predicted body height, this difference was statistically significant in two of the three predictive equations. The relative predicted length of the upper limbs (0.442BH), arms (0.189BH), lower limbs (0.515BH), thighs (0.257BH) and calves (0.251BH) corresponds with the predicted length of these segments. Actual trunk length (0.544BH) and forearm length (0.166BH) is longer than the predicted length. Based on the analysis of the body segments of the gymnasts we can say that the gymnasts have a longer trunk, medium long upper limbs and shorter lower limbs.

Keywords: *artistic gymnastics, body height, body segments, predictive equations.*

INTRODUCTION

Physical activity has a significant effect on the human body. Physical activity can lead to the development of physical abilities and skills, the overall physical condition and morphological structure of our body. Athletes train for several hours a day. This, along with the early specialization in sport, leads to concerns about the negative effects of high intensity movement load on physical function and construction. One of the ways to monitor these potential changes is to use prediction or estimation of the body height, which is vital for assessing the growth process or detecting any growth abnormalities. Furthermore, we can observe the impact of the external environment (e.g. physical activity, high physical load, etc.) or predict the final height and the level of somatic development.

The most commonly used methods for predicting the body height are the developmental morphographs and the correlation and regression analysis of the relationships between the values of the variables found in different periods of the ontogenesis. There are many variants of these two basic methods (Lebl & Krásničanová, 1996). Some variants combine the actual height at a given age by the biological or bone age to calculate the most accurate body height prediction (Tanner, Healy, Goldstein, & Cameron, 2001). The prediction of the body height can also be attained using the parental body height. This method was first used in 1889 by Galton, who came up with the concept of so-called parental middle height or Mid-parental height/MPH (Riegerová, Přidalová, & Ulbrichová, 2006). This concept was later further developed by Gray's equation, which was then modified by Kališová and Riegerová (1988) in order to correspond with the secular trend. Another variant of the calculation is the so-called adjustable Mid-parental height (Tanner, Goldstein, & Whitehouse, 1970). This equation includes the difference between a male and female body height, which represents the number 13 in the equation. The ± 10 cm range indicates the endpoints of the offspring, with an accuracy of 95%. Due to the calculation accuracy, it is appropriate to combine several methods for predicting the body height. Attaining the same or similar results with the maximum deviation of 5%, it is possible to consider the calculated final height as correct (Lébl & Krásničanová, 1996; Riegerová et al., 2006).

In relation to artistic gymnastics, the influence of intense training and the development of the male and female gymnasts is often being discussed. Gymnasts are trained up to 35 hours per week (Chrenko, 2017). Daly, Rich, Klein, and Bass (1999) calculated that during one gymnastic training the gymnasts perform on average 102 landings on their upper extremities and 217 landings on their lower extremities, with the impact force ranging between 3.6 and 10.4 times of body weight.

Riegerová et al. (2006) explains that genetic factors affect the body height by 80%, while the environment affects it only by 20%. Although most of the studies focus on the question how the body development and body height are affected by intense mechanical stress in female gymnasts (Havlíčková, 1993, Weimann, Witzel, Schwidergall, & Böhles, 1998), the same trends can also be observed in male gymnasts. Previous studies support that the typical figure of a gymnast is of lower growth and leaner compared to the normal population (Georgopoulos et al., 2012; Richet al., 1992).

Based on a comparison of somatic characteristics of the best gymnasts with lower-level gymnasts, Cleassens et al. (1991) found that the best ones differed in their lower height and lower weight and had shorter forearms. In relation to the lower body height, body weight and the tendency towards an ectomorphic body type of the gymnasts, Pavlík (2003) presented a comparison of somatometric parameters of Czech gymnasts competing in 1969, 1993 and 1996. The body height of the gymnasts dropped to 166 cm from the previous 170.2 cm and the body weight dropped from previous 67 kg to 62.1 kg. The authors suggested that the change in somatic parameters reflects the demand for more difficult and more dynamic routines. However, more recent results showed the average body height of the gymnasts somewhat higher than 170 cm (n = 101). Nevertheless, those values are still low compared to the values of the general European population (Šibanc, Kalichová, Hedbávný, Čuk, & Pajek, 2017).

Even the most recent sources (Burt, Green, & Naughton, 2017; Malina et al., 2013) report that there is much less knowledge of the load and growth of male gymnasts than there is of female gymnasts. Malina et al. (2013) note that with regards to the segmental structure of the body of the gymnasts, the findings are very limited.

They recapitulate that most authors only state that the lower limbs of the legs tend to be shorter, or mention the information about the sitting height. More detailed information about the lower limb segments is missing, same applies to the upper limbs. Siatras, Skaperda, and Mameletzi (2010) proved high reliability of anthropometric measurements such as segment lengths, breadths, circumferences, and skinfold thickness using portable and easy-to-use instruments. Therefore, they recommend this method as a suitable method for monitoring the growth of individual body segments of artistic gymnasts.

The aim of our study is to contribute to these findings and based on the analysis of anthropometric measures to find out whether the attained body height of elite artistic gymnasts from the Czech Republic corresponds with the predicted body height. Also, the objective is to compare the actual length of selected body segments with their predicted lengths.

METHODS

The sample was comprised of eleven male gymnasts (n = 11) aged 19 to 53 with average age of 33 ± 11.5 years, body height 174.9 ± 4.1 cm and weight 71.5 ± 5.13 kg (Table 1). Gymnasts included in the sample had to meet the following criteria: 1. finished physical growth, 2. intense gymnastic training 5 times a week for at least 12 years, 3. participation in competitions at international level. Most gymnasts started specializing and training intensively between the ages of 5 and 7 and their active gymnastic career ended mostly between the ages of 22 and 25. The weekly workload of the test subjects (TS) was between 15 and 30 hours.

Table 1
Characteristics of test subjects (TS).

TS	Age	Start gym.	End gym.	Time gym.	Mother's	Father's
TS 1	37	7	27	20	166	174
TS 2	52	6	24	18	172	176
TS 3	26	10	22	12	159	162
TS 4	27	7	24	17	168	180
TS 5	22	7	22	15	168	174
TS 6	19	6	19	13	160	175
TS 7	27	5	25	20	165	180
TS 8	38	7	22	15	165	177
TS 9	41	5	30	25	167	180
TS 10	53	5	33	28	158	178
TS 11	21	4	21	17	158	175
average	33.0	6.3	24.2	18.2	164.2	175.5
SD	11.47	1.54	3.94	4.65	4.51	4.83
x min	19	4	19	12	158	162
x max	53	10	33	28	172	180

A questionnaire and anthropometric measurement were used to collect the necessary data. The questionnaire served to collect personal data in respect of training and parental height. As for the anthropometric measures, the actual body height and the lengths of the following segments were obtained: trunk, upper limbs, arms, forearms, lower limbs, thighs, calves. The gymnasts were measured using a standardized anthropometric devices (anthropometer for measuring the vertical dimensions of the human body, sliding caliper featuring a double sided measuring scale and sitting chair). A standardized methodology was used to determine the length dimensions (Riegerová et al., 2006; Steward et al., 2011). M23 – M56a = segment specification according to Riegerová et al. (2006).

The measured anthropometric parameters were the following:

1. Physical Height (PH): The default position was standing up straight with the back, buttock, and heels touching the wall. The head was held up straight (so-called Frankfurt Horizontal) and did not touch the wall. The height was measured from the ground to the vertex.

2. Sitting height/trunk length (M23): The vertical distance of the vertex (v) from the sitting area was measured. The trunk was held up straight, the head in Frankfurt Horizontal; the thighs resting on the sitting area, knees bent at right ankles.

3. Length of the entire upper limb (M45): The direct distance of the acromial point from the dactylion point of the limb (a-da) was measured.

4. Arm length (M47): The direct distance of the acromial point from the radial point was measured.

5. Forearm length (M48): The direct radial point distance from the stylion point (r-sty) were measured.

6. Length of the entire lower limb (M53): The direct distance of the iliospinal point from the foot was measured.

7. Thigh Length (M55): The direct distance of the iliospinal point from the tibial point (ti) to the external lateral knee joint was measured.

8. Legs length (M56a): The direct distance of the tibial point spacing from the sphyrion point was measured.

To predict the body height, three different equations were used, all of which were based on the parental body height.

PH1 is predictive equation according to Gray (1988).

PH2 is predictive equation according to Kališová and Riegrová (1988).

PH3 is predictive equation calculating with the adjusted parental height (Tanner, Goldstein, & Whitehouse, 1970).

PH1: Son = (1.08 · Father's height + Mother's height) / 2

PH2: Son = (111.1 % Mother's height + 102.4 % Father's height) · 0.5

PH3: Son = [Father's height + (Mather's height + 13)] / 2 ± 10 cm

Due to our research being focused on men only, we always used the equation to calculate the height of the son.

To compare the measured lengths of individual body segments, the relative lengths of the segments (= ratio of segment length to body height) were calculated and compared with relative lengths of segments as reported by Chaffin and Andersson (CHA) (in Herman, 2007) (Table 2). The actual relative lengths of the segments were also compared with the anthropometric indexes by Brugsch (B) (Schmeister, 2011) (Table 3). Brugsch defined the values limiting the mid-lengths of the trunk, lower, and upper limbs. For statistical comparison the average value $\bar{x}$ of this range was used.

Table 2
Relative lengths of body segments (ratio of segment length to body height) in general population according to Chaffin and Andersson (in Herman, 2007).

Segment	Length of
Trunk	0.520
Upper limb	0.440
Arm	0.186
Forearm	0.146
Lower limb	0.530
Calve	0.246
Thigh	0.245

Table 3
Classification of anthropometric indexes of relative segment lengths (ratio of segment length to body height) for men in the general population according to Brugsch (edited by Schmeister, 2011). x̄ Men = the mean value of the range.

Classification by Brugsch	Men	x̄ Men
Metriocormic (Medium long trunk)	(0.511–0.520)	0.516
Brachycormic (Medium long upper limbs)	(0.441–0.445)	0.443
Metrioscelic (Medium long lower limbs)	(0.536–0.540)	0.538

The collected data was processed in Microsoft Excel 2016 and Statistics 12. Based on the results of the normality tests, for further statistical data processing parametric tests, namely the t-test at the level of probability 5% were used.

RESULTS

Anthropometric measurements results

The results of the anthropometric measurements of the research sample are summarised in Table 4.

Results of body height prediction

To calculate the predicted height (PH) of the probands three different equations - PH1, PH2, and PH3 were used. The calculated predicted heights (PH) were subsequently compared with the measured actual body height (BH) of the test subjects (Table 5, Figure 1).

As seen in Figure 1, it is apparent that using certain prediction equations, the actual BH of some tested subjects (TS) corresponds with the predicted body height or is even higher (TS 1, TS 2, TS 3, TS 9, TS 10 and TS 11). In TS 4 – TS 8 the body height is lower than all predicted values. The biggest difference between the PH and BH can be seen in TS 4 and TS 5, where the predicted body height obtained using the prediction equations PH2 is up to 14 cm higher than the actual body height.

The measured lengths of individual body segments, except from the absolute values (Table 4), are also given in the relative values, i.e. in relation to the BH (Table 6), in order to provide better interindividual comparison. Even Chaffin and Andersson (In Herman, 2007), as well as Brugsch (In Schmeister, 2011), whom our data was compared with, indicate the relative lengths of body parts. Brugsch only specifies the lengths of the trunk, lower limbs and upper limbs, and not the individual segments. For this reason they are missing from in Table 6.

Table 4
Results of anthropometric measurements of test subjects - the length of body segments (cm).

TS	Body	Sitting	Upper	Arm	Forearm	Lower	Thigh	Calf
TS 1	176	97.7	79	34.5	31	96.9	43	47
TS 2	181	99	78	32	30	101.6	45.5	49
TS 3	172.2	93.6	75	32	27	91.7	40.5	44.5
TS 4	171.7	94	76.6	35	29	93.2	41	45.5
TS 5	168.5	94.5	76	33.5	28	96.4	45.3	44.5
TS 6	172.5	95	74.4	30	30	89.2	42.2	40.3
TS 7	176	96	77.2	35.4	29	94.2	45	42.3
TS 8	174	96.5	73.5	31.4	27	93.8	45	42
TS 9	183.4	99	83	35.5	32	106.7	54	45.5
TS 10	176	92	78	32	27	92.9	45	41
TS 11	173	90	79	33	30.5	96.7	48	42
average	174.9	95.2	77.2	33.1	29.1	95.7	45	44
SD	4.1	2.7	2.5	1.7	1.7	4.6	3.6	2.6
x min	168.5	90	73.5	30	27	89.2	40.5	40.3
x max	183.4	99	83	35.5	32	106.7	54	49

Table 51
Actual Body Height (BH) and Predicted Body Height (PH1 - according to Gray (1988), PH2 – according to Kališová and Riegrová (1988), and PH3 – according to Tanner, Goldstein, & Whitehouse, 1970) of the gymnasts.

TS	BH (cm)	PH1 (cm)	PH2 (cm)	PH3 (cm)
TS 1	176.0	177.0	181.3	176.5
TS 2	181.0	181.0	185.7	180.5
TS 3	172.2	167.0	171.3	167.0
TS 4	171.7	181.2	185.5	180.5
TS 5	168.5	178.0	182.4	177.5
TS 6	172.5	174.5	178.5	174.0
TS 7	176.0	179.7	183.8	179.0
TS 8	174.0	178.1	182.3	177.5
TS 9	183.4	180.7	184.9	180.0
TS 10	176.0	175.1	178.9	174.5
TS 11	173.0	173.5	177.4	173.0
average	174.9	176.9	181.1	176.4
SD	4.1	4.0	4.1	3.9
x min	168.5	167.0	171.3	167.0
x max	183.4	181.2	185.7	180.5

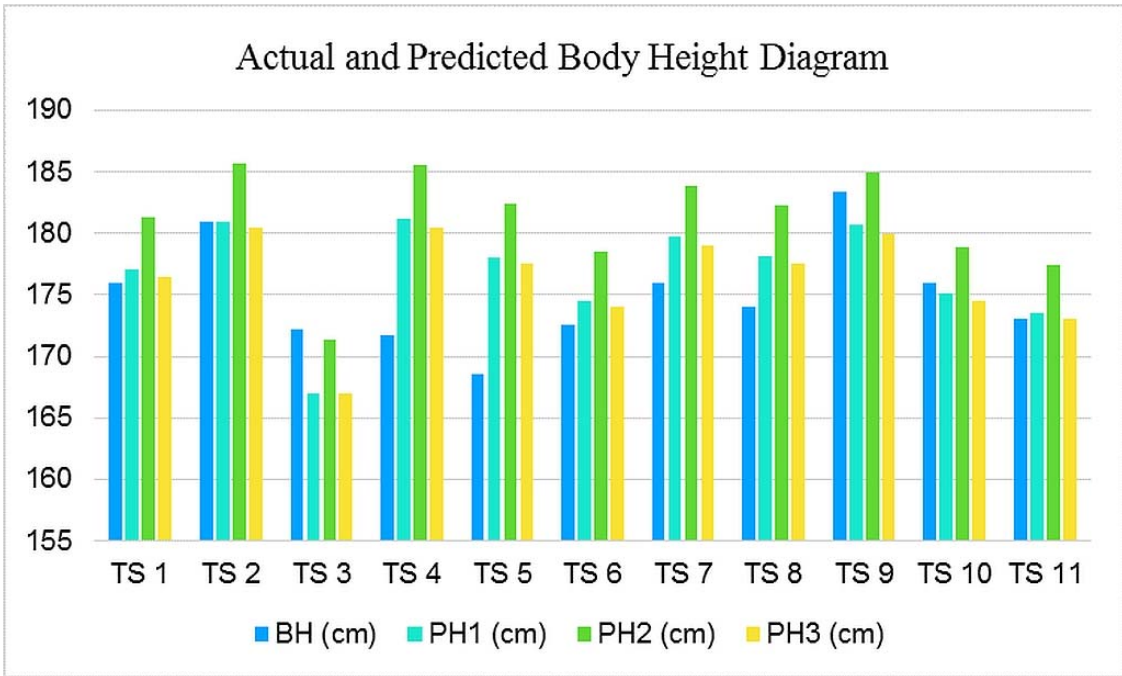

*Figure 1.*Comparison of the Actual Body Height (BH) and Predicted Body Height, (PH1 - according to Gray (1988), PH2 – according to Kališová and Riegrová (1988), and PH3 – according to Tanner, Goldstein, & Whitehouse, 1970) in test subjects (TS)

Table 62

Actual relative length of the body segments of gymnasts (ratio of segment length to body height); CHA = Predicted Relative Length of Segments according to Chaffin – Andersson, B = Predicted Relative Length of Segments according to Brugsch. M23 – M56a = segment specification by Riegerová et al., (2006) - length of Body Segments/Body Height.

TS	Trunk (M23)	Upper limb (M45)	Arm (M47)	Forearm (M48)	Lower limb (M53)	Thigh (M55)	Calf (M56a)
TS 1	0.555	0.449	0.196	0.176	0.506	0.244	0.267
TS 2	0.547	0.431	0.177	0.166	0.525	0.251	0.271
TS 3	0.544	0.436	0.186	0.157	0.508	0.235	0.258
TS 4	0.547	0.446	0.204	0.169	0.507	0.239	0.265
TS 5	0.561	0.451	0.199	0.166	0.504	0.269	0.264
TS 6	0.551	0.431	0.174	0.174	0.484	0.245	0.234
TS 7	0.545	0.439	0.201	0.165	0.497	0.256	0.24
TS 8	0.555	0.422	0.18	0.155	0.484	0.259	0.241
TS 9	0.54	0.453	0.194	0.174	0.452	0.294	0.248
TS 10	0.523	0.443	0.182	0.153	0.58	0.256	0.233
TS 11	0.52	0.457	0.191	0.176	0.618	0.277	0.243
average	0.544	0.442	0.189	0.166	0.515	0.257	0.251
SD	0.012	0.010	0.010	0.008	0.044	0.017	0.013
CHA	0.520	0.440	0.186	0.146	0.530	0.245	0.246
B	0.515	0.443	-	-	0.538		-

Table 7
T-test for the Actual Body Height (BH) and Predicted Body Height (PH1 - according to Gray (1988), PH2 – according to Kališová and Riegrová (1988), and PH3 – according to Tanner, Goldstein, & Whitehouse, 1970).

Variable	T-test for dependent samples, Differences significant at the level p <.05000									
	Average	SD	N	Dif.	SD (dif.)	t	sv	p	Int. reliab. (-95.000%)	Int. reliab. (+95.000%)
BH	174.936	4.065								
PH1	176.886	4.235	11	-1.949	4.569	-1.415	10	0.188	-1.121	5.019
BH	174.936	4.065								
PH2	181.082	4.330	11	-6.146	4.626	-4.406	10	0.001	3.038	9.254
BH	174.936	4.065								
PH3	176.364	4.063	11	-1.427	4.482	-1.056	10	0.316	-1.584	4.438

Table 83
T-test for the actual and predicted lengths (PL) of individual segments according to Chaffin and Andersson (PL1) and Brugsch (PL2), M23 – M56a = segment specification by Riegerová et al., (2006).

Variable	T-test for dependent samples, Differences marked at the significance level p <.050									
	Average	SD	N	Dif.	SD (dif.)	t	sv	p	Int. reliab. (-95.00%)	Int. reliab. (+95.00%)
Trunk length (M23)	95.209	2.815								
PL1- trunk	90.967	2.217	11	4.242	2.189	6.429	10	0.000	-5.713	-2.772
Trunk length (M23)	95.209	2.815								
PL2- trunk	90.180	2.198	11	5.029	2.185	7.634	10	0.000	-6.497	-3.561
Upper limb length (M45)	77.245	2.637								
PL1–Upper limb	76.972	1.876	11	0.273	1.872	0.484	10	0.638	-1.531	0.984
Upper limb length (M45)	77.245	2.637								
PL2–Upper limb	77.497	1.889	11	-0.251	1.872	-0.445	10	0.666	-1.006	1.509
Lower limb length (M53)	90.064	7.941								
PL1–Lower limb	92.716	2.259	11	-2.653	8.151	-1.079	10	0.306	-2.823	8.129
Lower limb length (M53)	90.064	7.941								
PL2–Lower limb	94.116	2.294	11	-4.052	8.159	-1.647	10	0.131	-1.429	9.534
Arm length (M47)	33.118	1.814								
PL1-Arm	32.538	0.793	11	0.580	1.782	1.080	10	0.306	-1.777	0.617
Forearm length (M48)	29.136	1.733								
PL1-Forearm	25.541	0.622	11	3.596	1.492	7.991	10	0.000	-4.598	-2.593
Thigh length (M55)	44.955	3.720								
PL1-Thigh	42.859	1.044	11	2.095	3.156	2.202	10	0.052	-4.216	0.025
Calf length (M56a)	43.964	2.694								
PL1-Calf	43.034	1.049	11	0.929	2.463	1.251	10	0.239	-2.584	0.726

It is apparent from the results that the actual trunk length in probands is higher than the predicted length. The average trunk length of the research sample is 4 to 5 cm greater than the average predicted length.

The average actual length of the upper limbs is higher than the predicted length according to CHA, but is lower than the predicted length according to B. In some probands, the actual length of the upper limbs is higher than both predicted lengths.

The average actual length of the lower limbs is lower than the predicted length according to both CHA and B. The average predicted length of the lower limbs is 2.66 – 4.06 cm greater than the actual lengths. However, it is obvious that the research sample also includes gymnasts whose length of the lower limbs is longer than both predicted ones.

To answer the question whether the actual body height of Czech elite artistic gymnasts corresponds with the predicted height, a statistical comparison using the t-test was performed (Table 7).

The statistically significant difference ($p < .05$) between the actual and predicted body height, which was calculated using the PH2 equation, was proved.

The calculation of the statistical significance of the differences (Table 8) was chosen to evaluate the question of how the length of the individual body segments corresponded to their predicted lengths (PL) according to Chaffin and Andersson (PL1) and Brugsch (PL2).

DISCUSSION

As the results showed, there is no significant difference between the predicted body height PH1, PH3, and the actual body height. The body height of the probands mostly corresponds with the Mid-parental height PH3. Considering the deviation of the predicted body height of ± 10 cm, which is given by this equation, it is evident that the body height of the gymnasts lies within this limit. These results correspond with the findings of Georgopoulos et al. (2012), according to which gymnasts reach lower body height than their genetic predispositions determine, however the final body height is still within the norm.

When comparing the obtained results with the results from other authors, who focused on the same topic, the present study revealed that the average body height of our tested gymnast (174.9 ± 4.1 cm) was higher than the average body height of the gymnasts in other studies. When comparing the results with a study by Cleassens et al. (1991) that included a larger number of tested subjects (n = 165), the average height of sample group is 7.9 cm higher. Latest results from the World Cup 2015 (Šibanc et al., 2017) show that the current gymnastic elite is by average 5 cm shorter than our research sample. In accordance with Malina et al. (2013), it can be assumed that the differences in the average body height of gymnasts in the studies can be affected by the number of tested subjects, their age, level of performance and their nationality, which is associated with their genotype.

Due to the fact that the research group consisted of Czech gymnasts, their height was compared with the average body height of the Czech population. The current average body height of Czech men is 178.8 cm, according to Kopecký, Kikalová and Charamza (2016). This average body height of men was determined on the basis of the body height measurement in 973 males aged between 19 and 94 years, which was implemented between 2013 and 2015. The average body height of the sample group is therefore 3.9 cm lower than the current average of the Czech male population.

When comparing the average body height of the fathers of the tested gymnasts (175 cm) with the average body height of the male Czech population (178.8 cm), results showed that the fathers' body height was below average. Baxter Jones, Helms, Maffulli, Baines-Preece and Preece

(1995) also found that the parents of gymnasts have lower body height than the parents of i.e. swimmers or tennis players.

When evaluating the validity of the predictive equations, we came to the same conclusions as Caska (2016), who showed a better match between the predicted and the achieved body heights when using the equation with the adjusted mid-parental height (PH3). This method of predicting body height is also mentioned in Malina et al. (2013). According to Lebl and Krasničanová (1996), the predictive calculation can be considered correct if the results match with the deviation of 5%. This condition corresponds with the results of PH1 and PH3. Therefore, it can be assumed that these predictive equations are more accurate than the equations by Kališová and Riegrová (PH2). However, it is advisable to verify the accuracy of the used calculations on a larger sample and control groups, or use different methods to perform to predict body height to verify the accuracy of the calculations.

As regards the anthropometric characteristics of the individual segments, a statistically significant difference between the actual and predicted length was found in the trunk. The actual length of the segment in gymnasts is greater than the predicted length according to CHA ($p = .000$) and B ($p = .000$).

There was no statistically significant difference between the actual and predicted length of the upper limbs (CHA: $p = .639$; B: $p = .666$). The same was found for the actual and predicted length of the lower limbs (CHA: $p = .306$). The difference in the average length of lower limbs and the predicted length according to B is higher (4.05 cm), yet no statistically significant difference was found ($p = .131$).

The data provided by Chaffin and Andersson allowed us for even more detailed comparison of the individual segments of the upper and lower limbs. No statistically significant difference was found in the actual arm length when compared to the predicted arm length PL1 (CHA: $p = .306$). On the other hand, a statistically significant difference was found when comparing the forearm lengths (CHA: $p = .000$). In this case, the average actual length of the forearm was 4.4 cm longer than the predicted length PL1.

For the lower limb segments, the actual length of the calves and the thighs was moderately higher than the predicted lengths. However, this difference was not statistically significant (CHA calf: $p = .239$; CHA thigh: $p = .052$). The fact that the total length of the lower limb was 2.7 - 4.1 cm less than the predicted length could be explained by the specific measurement methodology. The length of the lower limb included the ankle-floor distance, which could have been different in the tested persons but we did not measure it separately. The results could also be affected by individual differences within the relatively small research sample, as shown by the standard deviations in the lengths of lower limbs, thighs and calves.

When comparing our data regarding the body length parameters of gymnasts with previous studies, it is obvious the similarity of some results. Daly, Rich, Klein, & Bass (2000) focused on body length parameters of prepubertal and early pubertal male gymnasts ($n = 31$), that they compared with a control group. The authors reported a lower overall body height of gymnasts given by the shorter lower limbs, because the trunk length of the gymnasts corresponded with the trunk length of the control group. Even Rich et al. (1992) and Buckler et al. (1977) came to the same conclusion when they stated that the smaller figure is due to the shorter lengths of the lower limbs, not the length of the trunk. These results correspond with our results of shorter lower limbs in relation to the body height.

The lengths of the humerus, radius, femur and tibia bones were shorter in gymnasts than in the control group (Daly et al., 2000). Siatras, Skaperda, and Mameletzi (2009) found that the arms and legs of gymnasts were shorter compared to swimmers and non-athletes. Our results showed that the lengths of these segments correspond to the predicted lengths, according to Chaffin and Andersson, with only the forearm being significantly longer than assumed. These different results can be attributed to a relatively small sample of our research as well as to the choice of a control group that has been set up by Chaffin and Andersson.

The different proportions of the body parts of gymnasts in relation to their total body height may be associated with the different intensity of loading of the different body parts. Compressive load is applied to the musculoskeletal system during floor exercises, vault, and pommel horse. Parallel bars are a combination of compression and tension, horizontal bar and still rings exercises load the body primarily in tension (Chrenko, 2017). During floor exercises the highest values of compression force were recorded as follows: up to 3.6 times body weight (BW) in the upper limbs, and 10.4 BW in the lower limbs (Daly, Rich, Klein & Bass, 1999). In male gymnastics, the upper limbs, especially the wrists, are loaded on the pommel horse at around 1.85 BW (Fujihara, 2011). High-tension forces were recorded during exercises on still rings (Serafin, Golema, & Siemeński, 2008) and reported up to 11 BW. In regards to the different bone adaptation rates, Dowthwaite and Scerpella (2009) state that *"the mode of diaphyseal adaptation (endocortical expansion versus contraction) may be a function of the skeletal site, varying from bone to bone and within a single bone. High variability in the diaphyseal endocortical dimensions also suggests the potential for genetic influence."*

Lower body height in gymnasts is often associated with the negative effects of high-intensity mechanical loading. The main cause of this is primarily a high energy expenditure in comparison to poor nutrition, lower body fat mass and lower hormone levels. However, it should be noted that these results come mainly from research of female gymnasts. Studies on female gymnasts show that the levels of insulin-like growth factor 1 (IGF-1) and thyrixin are not different from that of other athletes or non-athletes due to intense training during pre-puberty and/or puberty (Daly et al., 1999; Daly et al., 2000; Weimann, Witzel, Schwidergall & Böhles, 2000). Some results show late maturation with lower growth rates in gymnasts (Georgopoulos et al., 2010; Weimann et al., 1998). However, according to Daly et al., (1999), Daly et al. (2000) and Ward, Roberts, Adams, Lanham-New & Mughal (2007), the growth rate of gymnasts was comparable to the growth rate of the controls. Canda (2016) in his case study followed the development of the anthropometric profile in two gymnasts. His measurements also showed that the gymnasts remained in their percentile growth curve during their long-term intensive training. Daly et al. (2000) suggest that bone growth may be affected by other factors as well, such as recurrent stress or acute bone injury.

Burt, Greene, Ducher, and Naughton (2013) claim that gymnastic training up to 30 hours per week and more has negative effects, but also positive effects as well. Even according to Jürimä, Gruodyte-Raciene, & Baxter-Jones (2018), these negative effects, which can result in lower bone accrual, are balanced by the positive effects of the gymnastic stress that has positive effects on bone development, primarily greater bone density and bone content. Dowthwaite and Scerpella (2009) specify the adaptive changes of the skeletal system of gymnasts during their growth as follows: enlargement of total and cortical bone geometry (+10 to 30 %) and elevation of trabecular density (+ 20 %) in the forearm, yielding elevated indexes of skeletal strengths (+20 to +50 %). Other sites exhibit more moderate geometric and densitometric adaptations (5 to 15 %). Burt et al. (2013) observed that these positive adaptations towards load are greater at the radius than tibia. Especially in the distal radius, with 10% to 12% more of the total bone density and content in pre-pubertal gymnasts than in controls. These results are supported by the results of comparable studies on other sports athletes. Heinonen, Sievänen, Kyröläinen, Perttunen, and Kannus (2001), who focused on the effects of extreme impact loading on the structure of lower limbs in triple jumpers, came to similar conclusions. It was found that this load improved the mechanical properties of the tissues, namely the mineral mass, size, and gross structural properties.

Based on findings, the authors (Daly et al., 2000) are of the opinion that lower body height of gymnast is rather the result of selection, as the body height deficit didn't increase with the higher workload. Natural selection bias, where physical predisposition plays an unavoidable role, can be commonly observed in sports (basketball, swimming, etc.) and it is also very important in artistic gymnastics. When monitoring the growth of gymnasts, the control groups often consists of non-athletes or swimmers (Siatras et al., 2009). It can be assumed that different anthropometric values will be found in swimmers as their performance depends on a quite different somatotype than of the gymnasts. The implementation of complex space-time movement structures is advantageous for smaller and lighter gymnasts (Burt et al., 2017). Therefore, it can be assumed that athletes with these physical characteristics will achieve excellent performances more easily and will be more successful. Individual gymnastic disciplines require different predispositions, which may be the somatotype or the anthropometric characteristics of the athlete. In today's gymnastics there is noticeable trend of gymnasts' specialization. Therefore, it is possible that among the elite gymnasts the variability of these physical factors will increase according to their specialization in different events. However, any relationship between the anthropometric characteristics of the segments or the somatotype of the gymnasts and their success individual disciplines in gymnasts competing in the World Cup 2015 was not confirmed (Hedbávný & Kalichová, 2015, unpublished).

Although gymnasts are usually smaller in size, our research sample was above average in comparison with the gymnasts from similar research. The cause of this result may be the fact that Czech men and women generally belong to the very tallest in the world (Grasgruber & Hrazdíra, 2013). The present study further revealed that the gymnasts surpassed the predicted body height and length of certain segments, and it was very individual. In our opinion, this fact is primarily due to their genetic dispositions, which were not significantly affected by the training. In any case, it is important to follow certain principles during high intensity training. It is necessary to monitor the level of training load and its consequences, especially fatigue, which can have negative effects on physiological functions of the body and thus both on the performance and the health of an athlete (Bernacikova, Čechovská & Novotný, 2018). As reported by Daly et al. (2007), exercises should be dynamic, diverse, applied rapidly and intermittently. The boundary load, when high-intensity exercises have still positive effects, is difficult to determine; several factors such as type of exercise and its intensity, duration, dietary intake, and other athlete-related variables such as age, gender, or maturity should be taken into account (Klentrou, 2016).

CONCLUSIONS

Unfortunately, due to the lack of publications dealing with anthropometric characteristics of artistic gymnasts and the lack of specification of the measurement methodology in these publications, it is not possible to compare our results further. In addition to this, the impact of intense gymnastic training on growth is mostly measured in female gymnasts rather than male gymnasts. The limitation of our study is primarily in a small research sample. However, its size corresponds with the possibilities of Czech gymnastics. A study with a larger sample group would be needed to generalize the results. Another limiting factor is the relatively large age range of our research sample. The results can be affected by the fact that some gymnasts competed 20 years ago when the Code of Points was different. With the development of the demands of the gymnastics in the course of two decades, changes in the optimal somatotype of the gymnast may be observed. Another limitation is the fact that the published studies often differ from each other in the methodology of both measuring and evaluating the results. It should also be kept in mind that the present research was conducted as a cross-sectional study. The results point to certain contexts, however a longer-term study following the changes in anthropometric characteristics in gymnasts and the control group would better demonstrate the extent to which intense training affects the body growth of gymnasts.

The results of this study can be briefly summarized as follows:

- The actual body height of gymnasts corresponds with the predicted body height, which was calculated using two different predictive equations: PH1 equation by Gray (1988) and PH3 equation with the adjusted mid-parental height; the highest match was in the case of PH3.
- The actual body height of gymnasts was lower than the predicted body height, which was calculated using the predictive equation PH2 by Kališová and Riegrová (2006).
- The actual length of segments corresponded with the predicted length of the upper limbs, arms, lower limbs, thighs and calves.
- The actual length of the trunk and forearms was significantly longer than the predicted length.
- The results indicated longer trunk, moderate upper limbs, and shorter lower limbs in gymnasts.

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