Original Article

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Longitudinal effects of swimming training on anthropometric characteristics in pre-adolescent girls

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Abstract: *Introduction*: The objective of this study was to evaluate the impact of a three-year swimming training program on selected anthropometric variables in a general population sample of pre-adolescent girls. *Material and Method*: The analysis included two groups of 10-year-old girls at the start of the study. Each research group consisted of 14 swimmers (body mass: 34.99 ± 2.77 kg; height: 146.00 ± 3.05 cm). The control group comprised girls (body mass: 37.93 ± 6.02 kg; height: 145.55 ± 3.88 cm) who participated only in mandatory physical education classes. The study spanned three consecutive years with measurements taken every six months. Selected anthropometric measurements were recorded. *Results:* Significant differences between the first and last measurements were observed for all anthropometric traits within both groups, with larger dimensions recorded at time 6. Besides height and body weight, the greatest difference was in shoulder width, with mean increases of 11.64 cm in the experimental group and 13.71 cm in the control group. No significant differences were found between the groups for most anthropometric measurements, except for body weight, where the control group gained an estimated 3.57 kg more than the swimmers over 6 years. *Discussion*: In conclusion, the study highlights that regular swimming training in young girls contributes to overall physical fitness and may positively influence certain body dimensions, such as chest width and foot width. However, the majority of growth in anthropometric traits appears to be driven by natural developmental processes rather than the effects of swimming training alone.

Keywords: swimming, anthropometric measurements, longitudinal study, girls

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INTRODUCTION

The positive impact of swimming on the human body is widely recognized. Notably, swimming from an early age helps correct posture defects, positively affects the cardiovascular system, and provides a foundation for combating obesity [1,2]. It is also important to emphasize that in order to achieve success in international sports competitions, swimming training should begin before puberty [3]. The consistent improvement in athletic performance pushes coaches and athletes aiming to compete on a global scale to seek increasingly innovative training solutions. This phenomenon is observed at all stages of training. The pressure to achieve results at international, national, and local competition levels is so high that, when faced with the choice between well-balanced training methods and increasing mileage during training sessions, the latter is often favoured. However, excessive biological strain on young athletes (in extreme cases) may lead to changes in the rate of sexual maturation and hinder athletic development. Exploring new training methods and understanding the impact of specific components on swimming performance in particular styles and distances appears to be a suitable approach for enhancing performance without disrupting the natural biological development of the child [4].

Most swimming coaches select children based on specific anthropometric characteristics (such as greater body height, longer upper and lower limbs, and narrower hips), which do not always translate to higher swimming efficiency later in life [5]. Early selection before puberty is considered a controversial practice. Researchers highlight that during late childhood (ages 9–11), it is essential to foster motivation and awareness of one's abilities and skills. Emphasis should be placed on deriving joy and satisfaction from sports, developing skills, and enhancing motor abilities, while minimizing experiences focused solely on achievement. This period is marked by emotional lability, mood swings, and the experience of both intense positive and negative emotions, as well as emotion regulation, consideration for peer opinions, and the ability to build psychological resilience [6].

In reality, promoting muscle strength development in young athletes is crucial for supporting the acquisition of motor skills, improving physical fitness, and consequently, enhancing sports performance, which will likely contribute to better health indicators, improved well-being, and reduced injury risk at a young age [7-11]. Scientific reports on the impact of swim training on anthropometric traits are inconclusive. Cross-sectional studies indicate that compared to a reference age group, young swimmers tend to have greater height and body mass [12,13], as well as higher muscle mass and lower fat mass [14]. Other studies have noted greater height among children practicing swimming compared to non-swimmers [15], though these studies often involved pre-selection for the sport. Additionally, evidence suggests that in the age range of 10–12 years, the height of children involved in swimming does not significantly differ from that of their non-swimming peers [16]. Similar findings apply to body mass, where no significant differences were observed between groups [17]. However, the length and circumference of the upper limbs tend to be greater in swimmers than in control groups [18], with the most substantial differences observed in foot length [19].

A factor analysis conducted in a sample of 11–12-year-old swimmers suggested that selection for this sport should consider two main factors: (1) a volume factor, which includes body mass, the Rohrer index, chest circumference, waist circumference, and circumferences of the arm, forearm, and calf; and (2) a height factor, which encompasses body height and the length of the upper and lower limbs [20]. Anthropometric variables have been repeatedly identified as significant determinants of young swimmers' performance. Mezzaroba and Machado (2013) pointed to a direct relationship between biological age and body dimensional differences affecting the development of basic kinematic indicators of swimming technique, such as stroke length, stroke rate, and stroke index [21]. The strong correlation between body height or total length and swimming proficiency during adolescence is confirmed by other studies [22]. It has also been noted that in swimming, individual selection occurs, as children and adolescents who swim tend to be taller on average than their peers who do not participate in sports or engage in other disciplines such as football, gymnastics, or tennis [23]. There is also evidence linking body composition with swimmers' propulsion abilities and, consequently, swimming performance [24,25]. However, studies on adult athletes indicate that while elite swimmers may achieve appropriate body dimensions [26,27], body height alone does not guarantee a competitive advantage [28]. Thus, improving swimming technique remains critical for achieving success [29].

Cross-sectional studies indicate that girls who practice swimming before puberty exhibit greater body height, higher body mass, more muscle mass, lower fat content, longer upper limbs, longer feet, and a longer torso. However, in most studies, the experimental group was pre-selected for swimming, which may bias the impact of the sport on these traits, as it is known that taller individuals with longer limbs, torsos, and feet are more desirable in swimming. In our study, participants took up swimming voluntarily, providing a more accurate picture of the effects of training and natural biological development on anthropometric characteristics, rather than pre-selection. This highlights a significant research gap and the need to further explore these changes.

According to the literature, systematic physical activity accelerates the transformation of cartilage tissue into bone, thus supporting growth processes. The skeletal bone tissue becomes more stable and resistant to injuries, also helping to correct posture defects [30]. Regular physical activity positively affects bone mineralization, contributing to bone hypertrophy. The unique nature of swimming, where the athlete adopts a horizontal position, alleviates the load on the skeletal system, potentially making swimming a top choice for achieving greater body length dimensions.

Therefore, the aim of this study was to assess how a three-year swimming training program for girls prior to puberty (without pre-selection) would influence selected anthropometric variables, and to compare these results with those of a control group that only participated in mandatory physical education classes. It is hypothesised that regular swimming training in the experimental group will result in increased torso length and upper limb length compared to the control group. It is also hypothesised that after the three-year period, the control group will exhibit a higher body mass compared to the experimental group. Answers to these questions may assist coaches and swimming instructors in selecting appropriate groups for swimming and in planning training programs to achieve elite performance without disrupting natural individual development. Additionally, the findings will inform coaches and instructors about the necessity of early selection for competitive swimming before puberty.

MATERIAL AND METHODS

Subjects

Two groups of 10-year-old girls were analyzed at the beginning of the study, each group consisting of 14 participants. The experimental group comprised competitive swimmers (body mass: 34.99 ± 2.77 kg; height: 146.00 ± 3.05 cm) training at Student Sports Clubs in Czestochowa, Poland. The selection of girls for these sports clubs was conducted without preliminary screening. At the start of the study (4th grade of primary school), the swimming group began formal swimming training, although they had previously acquired swimming skills through biweekly swimming lessons. The control group consisted of girls (body mass: 37.93 ± 6.02 kg; height: 145.55 ± 3.88 cm) who only attended mandatory physical education classes. The control group engaged in no additional systematic physical activities beyond these compulsory lessons. Both groups were matched to ensure homogeneity.

Ethics

In accordance with the Helsinki Declaration, all participants and their parents were informed about the purpose and methodology of the study, provided written consent for participation, and the study protocol was approved by the Research Ethics Committee of Jan Dlugosz University in Czestochowa, under approval number KB-2/2012.

Procedure

In the group of swimmers, training took place four times a week in the mornings (6:30–7:40). Each session began with a 10-minute warm-up outside of the pool. Once in the water, the swimmers completed a warm-up by swimming 200 to 400 meters using freestyle or backstroke. The main part of each session focused on refining technique across different swimming styles (freestyle, backstroke, breaststroke, and butterfly) and developing endurance. Swimmers performed sets that didn't exceed 400-meter intervals. Special attention was given to body positioning in each style, the efficiency of arm strokes, and maintaining consistent leg movements. Coaches worked on perfecting turns for each stroke and placed great emphasis on underwater swimming after pushing off the pool wall. Technical skill assessments in the different swimming styles were conducted over 100 and 200 meters of individual medley. To improve specific technical elements, coaches used specialized equipment like short and long fins, swim paddles, and resistance bands. Endurance training generally involved 400-meter intervals, primarily using freestyle. Focus was placed on maintaining a steady pace, executing proper turns, and keeping an efficient swimming stroke. Each session ended with stretching exercises on land, typically lasting around 7 minutes. These exercises were designed to increase the range of motion in the shoulder girdle and improve ankle flexibility. The ratio of endurance to speed work in each session was about 80:29. On average, participants swam 1,500 meters per day in the first year, about 2,000 meters in the second year, and approximately 2,500 meters in the third year. The training macrocycle was planned according to the guidelines set by the British Swimming Federation for girls aged 12. The study was conducted over three consecutive years, with measurements taken every six months between 8 AM and 12 PM (Monday). Body weight and height were measured using the MS4971 CHARDER scale with a precision of 0.1 kg and 0.5 cm, respectively. Anthropometric measurements included head length, head width, chest width, chest depth, shoulder width, hip width, upper limb length, arm length, hand width, lower limb length, foot width, and foot length. These measurements were taken on the right side of the body while standing (Frankfurt horizontal plane) using a Martin caliper (Baseline) with a precision of 1 mm, and circumferences were measured with a tape measure with a precision of 10 mm. The measurements were conducted in the nurse's office at the Primary School, performed by a qualified staff member from the Jan Dlugosz University Laboratory in Czestochowa. The swimmers' training macrocycle was planned according to the guidelines of the British Swimming Federation for girls aged 9-12 years and consisted of four morning training sessions per week. Each session lasted 70 minutes, with an aerobic to anaerobic task ratio of 80% to 20%. The average daily distance swum by participants was approximately 1500 meters in the first year, 2000 meters in the second year, and 2500 meters in the third year.

Analyses

To assess the significance of differences in selected anthropometric traits we performed a two-way analysis of variance (ANOVA), comparing measurements at first and sixth timepoint within the experimental and control groups, as well as between the groups. Subsequently, in order to estimate the proportion of variance in specific anthropometric features accounted for by measurement timepoint and swimming training, we performed multiple regression analyses for each anthropometric feature and compared the values of R2. In order to determine whether measurement timepoint and swimming training interact in influencing changes in anthropometric features we added their interaction to multiple regressions for each anthropometric outcome, followed by examination of the incremental R2 change. To assess the magnitude and direction of the effects of the predictors, we examined the beta coefficients and assessed the significance of differences based on non-overlapping standard errors. All analyses were conducted using stats for R [31]. Anthropometric features were z-standardized prior to regression analyses. In regression, we are able to estimate the R2 of group, independent of timepoint so in a way controlling for the direct effects of developmental changes. We run an additional sensitivity analysis to control for the non-independence of samples by using mixed-effects models, specifically incorporating random intercepts for individuals to account for the repeated measures over time. We then compared the values of marginal and conditional R2 to the original R2 values from uncontrolled multiple regressions. The marginal R2 reflects the proportion of variance explained by the fixed effects alone, while the conditional R2 represents the proportion of variance explained by both the fixed effects and the random effects combined.

RESULTS

Descriptive statistics

Upon visual examination of histogram plots and the skew statistics, all anthropometric measurements were normally distributed (Figure 1 and Table 1). Trajectories of anthropometric features across the 3 years of follow-ups are illustrated in Figure 2 and Table 1 and compared between the experimental and control groups. Significant differences between the first and final measurement were revealed for all anthropometric features in both groups, with greater dimensions noted at time 6 (Figure 1 and Table 1). Apart from height and body mass, the largest difference was observed for arm width, with mean differences between times 1 and 6 estimated as 11.64 cm in the experimental group and 13.71 cm in the control group. On the other hand, no significant between-group differences in anthropometric measurements were observed, except for body mass, where the controls were estimated to have gained 3.57 kg more than the swimmers over the course of 6 years.

Multiple regression analysis

Results of the multiple regression analysis estimating the proportion of variance in anthropometric features accounted for by the three predictor variables-- measurement timepoint, group membership and their interaction are presented in Table 2. The mean proportion of cumulative variance explained by the three predictors was 28%, ranging between 52% of the variance accounted for in lower limb length to 8% in head width. Group, whether experimental or control, was not observed to be a strong predictor, accounting for an average of 1% of the variance in outcome anthropometric measures. On the other hand, measurement timepoint accounted for a mean of 31% of the individual differences in anthropometric features. Based on beta coefficients, significant effects were observed for individual differences in chest width, upper limb length and foot width. For chest width and foot width, greater duration of swimming training was associated with increase in dimensions for these features, whereas for upper limb length, duration of follow-up was associated with inhibited growth of the limb. Despite the mixed model adjustment to account for non-independence of longitudinal samples, the marginal R2 values obtained from the controlled models did not significantly differ from the R2 values of the uncontrolled models, indicating that the fixed effects alone explain a similar proportion of the variance in outcome features (Table 3). This suggests that the inclusion of random effects did not substantially alter the explanatory power of the fixed effects in the models. Nevertheless, these findings warrant careful interpretation as the effect sizes associated with swimming training, aka group membership, are modest and not statistically significant, therefore a major proportion of changes in anthropometric features might occur as a function of developmental processes.

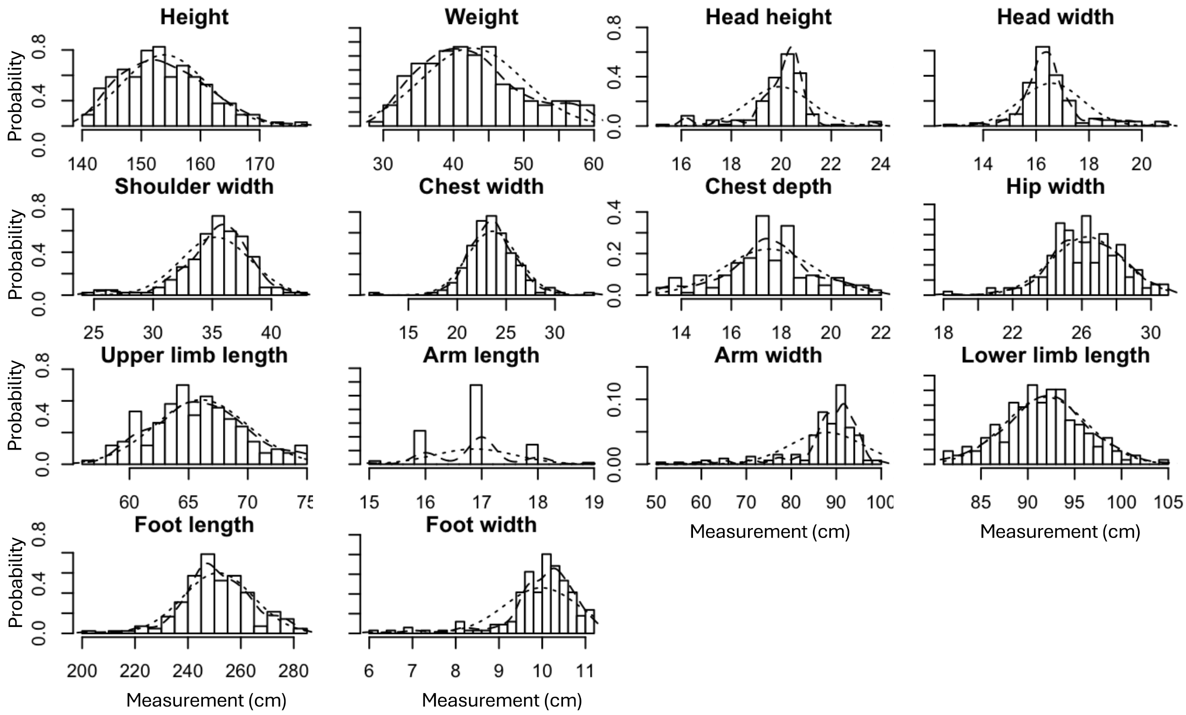

Figure 1. Histogram plots showing the distribution of anthropometric measures in centimeters.

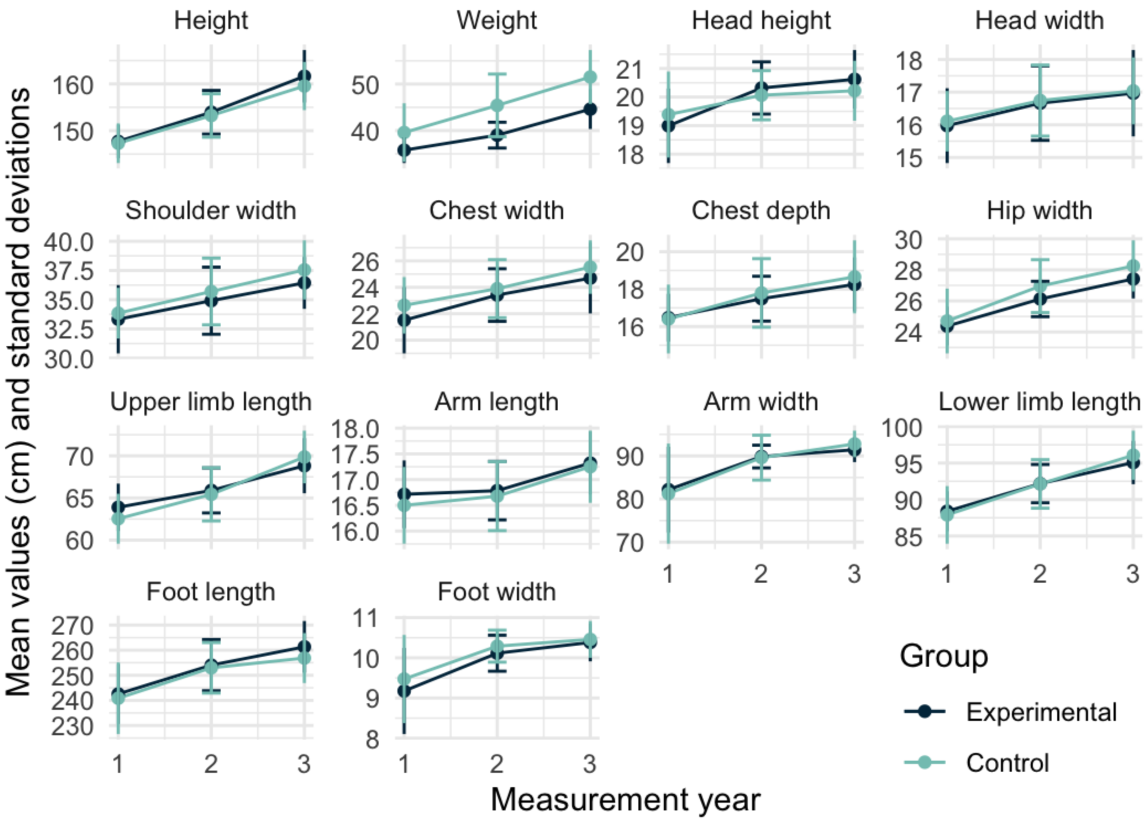

Figure 2. Mean trajectories of anthropometric features across the duration of the study, i.e., 3-years of follow-ups.

Table 1. Descriptive statistics of the first and sixth measurement timepoint, along with results of the ANOVA

V	G	Time 1				Time 6				ANOVA		
		M	SD	Range	S	M	SD	Range	S	Term	*F*	*p*
Body height	E	146.00	3.04	141.00 - 152.00	0.33	163.57	5.31	156.00 - 176.50	0.72	T	188.01	0.00
	C	145.54	3.88	140.00 - 153.50	0.40	160.86	5.30	152.00 - 170.00	0.16	G	1.76	0.19
										T×G	0.88	0.35
Body weight	E	34.99	2.77	31.40 - 40.10	0.33	46.43	4.09	42.40 - 55.60	1.04	T	105.04	0.00
	C	37.93	6.02	29.00 - 46.50	-0.06	52.94	5.71	44.10 - 59.50	-0.36	G	13.41	0.00
										T×G	1.91	0.17
Head height	E	18.99	1.33	16.10 - 20.30	-1.21	20.64	1.04	19.30 - 23.70	1.58	T	13.59	0.00
	C	19.16	1.75	15.00 - 20.50	-1.17	20.19	1.22	16.20 - 21.10	-2.41	G	0.15	0.70
										T×G	0.73	0.40
Head width	E	15.76	1.25	12.70 - 18.20	-0.55	16.99	1.34	15.60 - 20.80	1.67	T	16.16	0.00
	C	15.81	0.94	13.80 - 17.20	-0.39	17.00	0.91	16.00 - 19.70	1.68	G	0.01	0.92
										T×G	0.00	0.95
Shoulder width	E	32.80	3.01	24.40 - 35.80	-1.36	37.04	1.26	35.10 - 38.90	-0.04	T	41.56	0.00
	C	33.10	2.16	30.00 - 37.40	0.34	37.50	3.13	28.50 - 42.20	-1.35	G	0.33	0.57
										T×G	0.02	0.90
Chest width	E	21.43	1.66	18.20 - 24.00	-0.09	24.98	3.04	21.70 - 33.90	1.70	T	33.52	0.00
	C	22.44	2.16	18.00 - 26.60	-0.24	25.95	2.04	23.50 - 30.10	0.50	G	2.63	0.11
										T×G	0.00	0.98
Chest depth	E	16.19	1.38	13.60 - 18.30	-0.64	18.40	1.52	15.90 - 21.30	0.26	T	31.35	0.00
	C	15.94	1.83	13.10 - 19.30	0.17	18.81	1.98	13.90 - 21.60	-0.70	G	0.03	0.86
										T×G	0.53	0.47
Hip width	E	23.85	1.31	21.00 - 25.50	-0.80	27.85	1.09	26.50 - 30.50	0.88	T	101.55	0.00
	C	23.89	2.13	18.30 - 27.40	-0.91	28.49	1.66	25.00 - 30.80	-0.73	G	0.65	0.43
										T×G	0.49	0.49
Upper limb length	E	63.29	3.00	59.00 - 68.00	0.03	69.64	3.27	65.00 - 75.00	0.09	T	78.03	0.00
	C	61.71	3.12	56.00 - 68.00	0.22	70.29	3.24	66.00 - 75.00	0.25	G	0.30	0.59
										T×G	1.72	0.20
Arm length	E	16.64	0.74	15.00 - 18.00	-0.45	17.50	0.65	16.00 - 18.00	-0.78	T	18.15	0.00
	C	16.50	0.76	15.00 - 18.00	0.00	17.29	0.73	16.00 - 19.00	0.71	G	0.86	0.36
										T×G	0.03	0.85
Arm width	E	79.86	11.90	55.00 - 91.00	-0.85	91.50	2.98	87.00 - 95.00	-0.05	T	26.31	0.00
	C	79.14	13.50	50.00 - 94.00	-0.83	92.86	3.08	88.00 - 100.00	0.42	G	0.02	0.90
										T×G	0.18	0.68
Lower limb length	E	86.93	2.62	81.00 - 90.00	-0.77	96.07	2.95	92.00 - 102.00	0.35	T	129.34	0.00
	C	86.50	3.61	81.00 - 92.00	-0.10	96.86	3.55	92.00 - 105.00	0.73	G	0.04	0.84
										T×G	0.50	0.48
Foot length	E	23.87	1.31	20.20 - 25.70	-1.22	26.26	1.04	24.60 - 28.20	0.26	T	47.12	0.00
	C	23.69	1.46	21.10 - 26.30	0.12	25.79	1.02	24.50 - 27.70	0.61	G	0.99	0.33
										T×G	0.18	0.67
Foot width	E	8.87	1.31	6.00 - 10.20	-0.94	10.41	0.46	9.80 - 11.20	0.29	T	29.21	0.00
	C	9.20	1.30	6.50 - 10.80	-0.73	10.49	0.47	9.70 - 11.20	-0.18	G	0.63	0.43
										T×G	0.22	0.64

SV = variable, G = group; E = experimental group; C = control group; M = mean; SD= standard deviation; S = skew; T = time of follow-up

Table 2. Results of the multiple regression analysis

Variable	Model	R2	R2 change	Total adjusted R2	Beta	SE	T-value	*p*
Head height	Group	0.00	0.00	0.16	0.14	0.35	0.40	0.69
	Follow-up + Group	0.19	0.19					
	Follow-up x Group	0.21	0.02					
Head width	Group	0.00	0.00	0.08	0.04	0.36	0.12	0.91
	Follow-up + Group	0.14	0.14					
	Follow-up x Group	0.14	0.00					
Shoulder width	Group	0.02	0.02	0.22	0.10	0.33	0.30	0.76
	Follow-up + Group	0.26	0.24					
	Follow-up x Group	0.27	0.01					
Chest width	Group	0.02	0.02	0.23	0.39	0.33	1.17	0.24
	Follow-up + Group	0.28	0.26					
	Follow-up x Group	0.28	0.00					
Chest depth	Group	0.00	0.00	0.19	-0.14	0.34	-0.41	0.68
	Follow-up + Group	0.24	0.23					
	Follow-up x Group	0.24	0.00					
Hip width	Group	0.03	0.03	0.49	0.02	0.27	0.08	0.94
	Follow-up + Group	0.51	0.49					
	Follow-up x Group	0.52	0.01					
Upper limb length	Group	0.00	0.00	0.45	-0.40	0.28	-1.43	0.16
	Follow-up + Group	0.46	0.46					
	Follow-up x Group	0.48	0.02					
Arm length	Group	0.01	0.01	0.14	-0.20	0.35	-0.57	0.57
	Follow-up + Group	0.19	0.18					
	Follow-up x Group	0.20	0.01					
Arm width	Group	0.00	0.00	0.29	-0.09	0.32	-0.28	0.78
	Follow-up + Group	0.33	0.33					
	Follow-up x Group	0.34	0.01					
Lower limb length	Group	0.00	0.00	0.52	-0.10	0.26	-0.37	0.71
	Follow-up + Group	0.55	0.55					
	Follow-up x Group	0.56	0.01					
Foot length	Group	0.01	0.01	0.30	-0.14	0.32	-0.44	0.66
	Follow-up + Group	0.35	0.34					
	Follow-up x Group	0.35	0.00					
Foot width	Group	0.01	0.01	0.32	0.38	0.31	1.22	0.22
	Follow-up + Group	0.36	0.35					
	Follow-up x Group	0.36	0.00					

R2= proportion of variance explained; SE= standard error.

Table 3. Results of the mixed-effects regression model

Variable	Model	Uncontrolled R2	Marginal R2	Conditional R2
Head height	Group	0.00	0.00	0.45
	Follow-up + Group	0.19	0.18	0.66
	Follow-up x Group	0.21	0.20	0.68
Head width	Group	0.00	0.00	0.62
	Follow-up + Group	0.14	0.14	0.77
	Follow-up x Group	0.14	0.14	0.77
Shoulder width	Group	0.02	0.02	0.51
	Follow-up + Group	0.26	0.25	0.78
	Follow-up x Group	0.27	0.26	0.79
Chest width	Group	0.02	0.02	0.51
	Follow-up + Group	0.28	0.27	0.80
	Follow-up x Group	0.28	0.27	0.80
Chest depth	Group	0.00	0.00	0.63
	Follow-up + Group	0.24	0.23	0.89
	Follow-up x Group	0.24	0.23	0.89
Hip width	Group	0.03	0.03	0.29
	Follow-up + Group	0.51	0.50	0.86
	Follow-up x Group	0.52	0.50	0.86
Upper limb length	Group	0.00	0.00	0.35
	Follow-up + Group	0.46	0.45	0.88
	Follow-up x Group	0.48	0.47	0.90
Arm length	Group	0.01	0.01	0.58
	Follow-up + Group	0.19	0.18	0.78
	Follow-up x Group	0.20	0.18	0.78
Arm width	Group	0.00	0.00	0.20
	Follow-up + Group	0.33	0.32	0.59
	Follow-up x Group	0.34	0.32	0.58
Lower limb length	Group	0.00	0.00	0.26
	Follow-up + Group	0.55	0.53	0.90
	Follow-up x Group	0.56	0.54	0.91
Foot length	Group	0.01	0.01	0.41
	Follow-up + Group	0.35	0.33	0.80
	Follow-up x Group	0.35	0.33	0.80
Foot width	Group	0.01	0.01	0.14
	Follow-up + Group	0.36	0.35	0.54
	Follow-up x Group	0.36	0.35	0.53

R2 = proportion of variance explained.

DISCUSSION

This study aimed to evaluate the impact of a three-year swimming training program on selected anthropometric features in prepubescent girls, comparing the results with a control group that participated only in mandatory physical education classes. The findings revealed significant growth in various anthropometric measurements over the course of the study in both the swimming and control groups. However, while some growth patterns appeared similar between groups, the impact of swimming training on specific measurements warrants closer examination.

Our research observed an increase in body mass and height across both groups over a three-year period, consistent with findings reported by other authors in this field

[32]. A statistically significant increase in body mass was noted in favour of the control group. It can be inferred, therefore, that a three-year prepubescent swimming training regimen for girls may have contributed to a slower rate of body mass gain compared to non-training peers. Consequently, swimming may play a critical role in preventing excessive body fat accumulation and serve as an important factor in combating the commonly observed issue of childhood overweight [33]. However, this should be approached with caution, as the study did not specifically assess fat content in either the control or experimental groups. Additionally, the lower body mass among swimmers could contribute to improved performance, particularly during underwater phases following the start dive and turns. Researchers agree that a lean body shape is desirable in swimming, and such physique should be considered during the selection process for potential young athletes in the sport [34].

Other studies have shown that, among boys aged 10-12 who participate in swimming, the percentage of body fat and fat distribution across different anthropometric points did not significantly impact their performance over specific swimming distances. This suggests that in the prepubescent period, when an athlete is only beginning a specialized swimming training, technical and motor skills, which significantly improve as a result of training, are the primary factors influencing performance outcomes [35].

Nevertheless, scientific research shows that changes in body mass in prepubescent children due to additional physical activity are inconclusive. During the three-year observation, body mass changes were noted among swimmers as a result of swimming training, but only at the initial measurement stages [36]. It has been observed that additional physical activities, such as swimming, may significantly impact preventing excessive body mass increases [37]. Reports indicate that within the studied age range (10-12 years), body mass among boys and girls who participated in swimming did not significantly differ from those who did not engage in the sport [38]. Authors explain that the lack of significant change in young swimmers may primarily result from the aerobic nature of their activity. It could be assumed that aerobic exercise can be used to reduce body mass at this age; however, they induce only minor changes in body composition (e.g., BMI, body fat percentage). Other studies found no statistically significant correlations between BMI and the physical activity level of 12-year-olds [39]. It was also noted that BMI and fat tissue levels did not differ significantly between 10-year-old children participating in team sports and their peers who did not engage in extracurricular sports activities. Researchers agree that overall fat accumulation increases as physical activity levels decrease (approximately 2% difference) [40]. The impact of insufficient physical activity on fat accumulation in young women with a normal body mass has also been demonstrated [41]. The study indicated that the group of the most physically active women, who trained a selected endurance sport at least four times weekly, stood out most in terms of most analysed traits [42]. We must however approach the above research findings with some caution. All the children involved had been pre-selected for swimming, which could introduce biases in the interpretation of the results concerning the significant impact of swimming training on body weight reduction. As indicated in the literature, individuals with a slender physique are often preferred in competitive swimming to minimise water resistance [43]. Our findings demonstrate a marked difference in body weight between the control group and the experimental group. It can therefore be assumed that a three-year aerobic training programme contributes to developing a physique favourable for swimming while also reducing body fat content, which could, in turn, translate into improved swimming performance.

Our research suggests that swimming training may influence the increase in body height among the examined girls, a conclusion also reached by Knechtle [15]. In this study, the experimental group had been pre-selected for swimming. As we know, one of the primary characteristics considered during the initial selection process is the height of both the child and their parents [44]. In our study, the girls took up swimming voluntarily, without undergoing any prior selection. Therefore, we can infer that natural biological development and swimming training contributed to increased height parameters compared to peers who do not practice swimming. This effect can be partially explained by the health benefits associated with swimming. During swimming training, athletes spend most of their time in a horizontal position, which relieves pressure on the spine and, as demonstrated by other authors, accelerates bone mineralization [35].

Our results indicate that the swimmers initially exhibited longer upper limbs on average, consistent with findings from other authors [45]. However, after two years, this relationship favoured the control group. This may result from the influence of physical exercise on bone structure changes [46] or natural ontogenetic development rather than swimming training itself [29,47]. The effect of swimming training on upper limb length warrants further investigation in future studies. Increased upper limb length in senior swimmers correlates with better swimming performance, particularly in freestyle and backstroke, as well as butterfly stroke, as demonstrated by researchers [48]. Among young swimmers (aged 10-12), the lack of developed technique and coordination disorders in upper limb movements may lead to worse performance, especially in short-distance events. Swimming coaches emphasise that young athletes often neglect the correct upper limb technique during short-distance starts. To leverage efficient upper limb movement, it is crucial to establish proper water grip by maintaining a "high elbow" position during the underwater arm phase [48]. It can also be speculated that for children starting swimming training, inefficient arm movement may generate greater resistance and disrupt the upper limb cycle, both above and below the water's surface, more than for those with shorter upper limbs [37].

The results of this study indicate that swimming training may only affect selected somatic traits, such as body mass, height, and upper limb length. Other aspects of the athletes' body composition do not statistically differ from those of non-training girls. Other research has highlighted the influence of swimming training on the somatic structure [14,36]. Thus, it appears that the growth of other somatic indicators was due to natural development in the prepubescent period. This is considered a positive outcome, as it indicates that a three-year swimming programme does not adversely affect the natural physical development of young girls. While the body composition of elite adult swimmers differs significantly from non-swimmers, with swimmers having larger chest and shoulder dimensions and narrower hips [49], few studies have focused on the long-term impact of swimming on prepubescent children [50]. Most publications concern short-term studies on children involved in swimming, often with pre-selection for the sport [14]. Despite certain limitations, the present study expands knowledge about the effects of three-year swimming training on the somatic traits of young females. Our analyses suggest that monitoring changes in body mass, height, and length and width parameters among prepubescent swimmers in long-term studies is crucial to guiding coaches on which traits to focus on when shaping future swimmers. Therefore, we believe our findings can serve as a reference point for other researchers and guide future inquiries.

The results showed significant increases in all anthropometric features over the three years, regardless of whether the participants were in the experimental (swimming) or control group. This finding indicates that developmental processes, such as natural growth and maturation, play a prominent role in anthropometric changes during late childhood. Measurement timepoint accounted for a considerable proportion (31%) of the variance in anthropometric features, emphasizing the influence of natural growth. These results are consistent with previous research, which has shown that physical and skeletal development in children occurs predominantly as a result of biological maturation.

The multiple regression analysis indicated that group membership (swimming vs. control) was not a strong predictor of individual differences in anthropometric changes, explaining only a small proportion of the variance. This finding suggests that while swimming may have specific localized effects, such as changes in muscle development or limb length, the overall impact of swimming training on the measured anthropometric traits was modest compared to the natural growth processes. For example, while chest width and foot width showed greater increases with prolonged swimming training, upper limb length growth was somewhat inhibited. The latter result could be due to the nature of the swimming strokes practiced, where certain training activities may prioritize muscle strengthening over elongation of limbs. In our study, the swimming group predominantly performed tasks using so-called "long-axis" strokes, such as front crawl. Other researchers have noted that swimming in front crawl or backstroke may contribute to the elongation of the upper and lower limbs [21]. Achieving greater limb length, combined with the gradual acquisition of correct technique in children, is likely to result in improved athletic performance across various distances, particularly in front crawl and backstroke.

Our findings highlight a potential limitation in the practice of early selection based solely on anthropometric characteristics. While coaches often select children for swimming based on body dimensions such as height and limb length, this study suggests that growth patterns in prepubescent girls may not significantly differ between those who swim and those who do not, especially when training is introduced without pre-selection. This aligns with other research suggesting that early specialization in sports may not always predict future athletic success and can increase the risk of burnout or overuse injuries [51]. Based on the observation of our research findings, coaches should assume that a well-structured training process and the associated changes in body composition during this period will be far more important than early selection before puberty.

Furthermore, the results showed that swimming training had some positive localized effects on chest and foot width, which may relate to the sport's specific demands on upper body strength and foot propulsion in the water. The increased chest width could indicate better development of the upper body muscles, such as the pectoral muscles, which are crucial for strokes like butterfly and freestyle. Similarly, increased foot width may be a result of frequent use of the feet for kicking, which could potentially support swimming propulsion. However, it should be noted that these changes, while measurable, were modest, suggesting that while swimming has some specific impacts on body development, general growth trends dominate the anthropometric changes at this age.

One unexpected finding was the observed inhibition in upper limb growth in the swimming group compared to the control group. This may be due to the emphasis on muscle development rather than lengthening of the limbs, or it could be related to the training load and intensity, potentially affecting growth plates. Although these effects were small and require further investigation, they indicate the need for a balanced training approach that avoids excessive strain on young athletes.

The study's methodology, which included participants who took up swimming voluntarily without pre-selection, adds to the body of knowledge by providing insights into the effects of swimming on natural development, as opposed to studies involving athletes already selected based on favorable anthropometric characteristics. The findings suggest that systematic swimming training contributes positively to health indicators and physical fitness, although the changes in anthropometric traits may not be as pronounced as some may expect. It underscores the importance of using diverse criteria beyond body size and shape for talent identification and athlete development in swimming.

Overall, while this study contributes valuable information regarding the effects of swimming training on anthropometric development in girls, it is essential to consider some limitations. The sample size was relatively small, and the study was conducted within a specific cultural context, which may limit generalizability. Additionally, while swimming training was linked to some localized growth patterns, the study's design did not allow for the exploration of potential factors influencing growth, such as nutrition. Further longitudinal research with larger sample sizes and consideration of additional factors is needed to better understand the interaction between systematic training and natural growth processes.

CONCLUSION

In conclusion, the study highlights that regular swimming training in young girls contributes to overall physical fitness and may positively influence certain body dimensions, such as chest width and foot width. However, the majority of growth in anthropometric traits appears to be driven by natural developmental processes rather than the effects of swimming training alone. These results suggest that while swimming can be a beneficial physical activity for promoting health and fitness, early talent identification should not rely solely on anthropometric characteristics, as growth trends during childhood are highly variable and influenced by numerous factors.

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