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Relationship between anthropometric and motor characteristics and swimming performance over 400 meters freestyle in young swimmers

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Abstract

This study analyzes the effects of anthropometric and motor characteristics on the swimming performance of male swimmers aged 12-15 years. The aim of the study was to measure participants' shoulder width, grip strength, flexibility and aerobic endurance and to investigate the correlation of these data with swimming times over 400 meters freestyle. The study focuses on two age groups (12-13 and 14-15) and identifies the factors that influence performance in the different age groups. The anthropometric and motor characteristics of the participants were measured using a Tanita BC 418 bioelectrical impedance device and the data obtained were analyzed by a simple linear regression analysis. The results showed that shoulder width, hand grip strength, flexibility and aerobic endurance significantly affected performance in the 12-13 age group ($p<0.05$), while body weight, upper body length, muscle strength, flexibility and aerobic endurance more significantly affected performance in the 14-15 age group ($p<0.05$). The results of the study highlight that the characteristics that influence young swimmers' performance differ between age groups and therefore require group-specific and personalized training programs. These results provide important information for coaches and sports scientists to improve swimming performance.

Keywords: Anthropometric, motor performance, swimming, boys

Genç yüzücülerde antropometrik ve motorik özellikler ile 400 metre serbest yüzme performansı arasındaki ilişki

Öz

Bu çalışma, 12-15 yaş arası erkek yüzücülerin yüzme performansı üzerindeki antropometrik ve motorik özelliklerin etkilerini analiz etmektedir. Araştırmanın amacı, katılımcıların omuz genişliği, el kavrama kuvveti, esneklik ve aerobik dayanıklılık gibi özelliklerini ölçmek ve bu verilerin 400 metre serbest yüzme süreleri ile korelasyonunu araştırmaktır. Çalışma, iki yaş grubuna (12-13 ve 14-15) odaklanarak, farklı yaş gruplarında performansı etkileyen faktörleri belirlemektedir. Katılımcıların antropometrik ve motorik özellikleri, Tanita BC 418 bioelektrik impedans cihazı kullanılarak ölçülmüş ve elde edilen veriler, basit doğrusal regresyon analizi ile değerlendirilmiştir. Bulgular, 12-13 yaş grubunda omuz genişliği, el kavrama kuvveti, esneklik ve aerobik dayanıklılığın performansı önemli ölçüde etkilediğini ($p<0.05$), 14-15 yaş grubunda ise vücut ağırlığı, üst vücut uzunluğu, kas kuvveti, esneklik ve aerobik dayanıklılığın performansı daha fazla etkilediğini göstermektedir ($p<0.05$). Çalışmanın sonuçları, genç yüzücülerin performansını etkileyen özelliklerin yaş gruplarına göre farklılık gösterdiğini ve bu nedenle gruba özel ve kişiselleştirilmiş antrenman programlarına ihtiyaç olduğunu vurgulamaktadır. Bu bulgular, yüzme performansını artırmak için antrenörlere ve spor bilimcilerine önemli ipuçları sunmaktadır.

Anahtar Kelimeler: *Antropometrik özellikler, erkek çocuklar, motor performans, yüzme*

This study is based on a thesis.

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INTRODUCTION

Swimming is a sport suitable for both physical and mental well-being for every age group, serving as both a competitive sport and a recreational activity. As a healthy sport swimming has a characteristics of physical strength, technique, skill, and coordination combining them (Muratlı, 1997; Güler, 2000). Starting swimming from childhood and continuing through pre-adolescence and adolescence enhances various motor skills in children, including body composition, endurance, strength, and coordinative properties. Thus, swimming also lays the groundwork for athletic requirements needed in many other sports. Furthermore, for high performance in swimming, it is necessary to enhance athletes' anthropometric and motor characteristics from an early age (Bozdoğan & Özüak, 2003; Şentürk, 2018; Demirkan, et al., 2019).

Nowadays, initiatives aimed at encouraging children to engage in sports are in-creasing, and research on the effects and benefits of sports on children is being updated. Particularly, the benefit of swimming for children's physical, physio-logical, and psychological development, their orientation towards this sport, and studies related to swimming performance are attracting attention (Malina & Bouchard, 1991; Dal, 2011; Arslan et al., 2024).

Anthropometric and motor characteristics are identified in the literature as significant determinants of athletic performance (Zamparo, 2006; Özkadı, et al., 2022; Küçük & Söyler, 2024). Some variables related to swimmers' anthropometric characteristics can affect their swimming performance (Hue, et al., 2005; Barbieri, et al., 2012), and success in swimming is also closely related to the technical skills of athletes at every age (Dal, 2011; Nasirzade, et al., 2015). In competitive swimmers, anthropometric and motor characteristics vary depending on different swimming distances and styles, drawing attention to the importance of these characteristics for success in swimming events (Millet, et al., 2002). Therefore, physical and anthropometric factors supporting performance in swimming are monitored to identify the conditions of athletes, explore relationships to performance, and also to effectively utilize talent identification and training programs (Mitchell, et al., 2018). Indeed, the biological growth and development process during childhood and adolescence likely affects swimmers' success parameters and performance different levels (Lätt, et al., 2002).

At the 2020 Tokyo Summer Olympics, the difference between gold and silver medals in the men's 400 meters' freestyle was 0.16 seconds (FINA, 2023), highlighting how even marginal interactions can be critically important in elite swimming (Bond, et al., 2014). In competitions, while athletes may have similar performance capabilities, discovering even a 1% improvement in performance will have a significant impact on the future selection, direction, training, and competition outcomes of athletes (Hall, et al., 2012).

In this context, a range of literature has documented how anthropometric and motor variables can predict swimming performance in diversity (Morais, et al., 2012; Ingham, et al., 2013). Based on this, according to our careful literature review, there seem to be a lack of research specifically focusing on the relationship between 400m swimming performance and the anthropometric and motor characteristics of child and adolescent swimmers. The purpose of this study is to examine the interaction and relationship between some anthropometric and motor variables of male child and adolescent swimmers of different age groups and their performance in the 400 m freestyle swimming style.

METHOD

Research group (population-sample)

This research was conducted with the voluntary participation of 40 amateur competitive male swimmers aged between 12-15. The participants were selected based on their regular participation in swimming competitions and training sessions. Specifically, they were required to engage in land training 2-3 days a week and swimming training 3-6 days a week, each session lasting at least 30 minutes. The purpose of the study was thoroughly explained to the athletes and their parents, and written consent was obtained from the parents. The selection criteria included age, training frequency, and competitive experience to ensure a homogenous study group. Prior to the commencement of the study, approval was obtained from the Hitit University Non-Interventional Ethics Committee (Decision Number: 2018-11), ensuring the study adhered to ethical standards. Before starting the measurements and tests, participants were informed in detail about the testing methods and procedures. To maximize accuracy and performance, efforts were made to enhance the participants' motivation and willingness to perform at their best. This included verbal encouragement and creating a supportive testing environment.

Data collection tools

Anthropometric Measurements: In the study, anthropometric and motor measurements were primarily conducted. For body weight and height measurements, as well as for body composition analysis, the Tanita BC 418 bioelectrical impedance device was used. For measuring upper body length, leg length, single arm length, and biceps flexion circumference, a non-elastic tape measure of the Aptamil brand was employed. Additionally, for shoulder, pelvis, elbow, and knee diameters, an anthropometric set from Holtain was utilized (Miller, 2006). The flexibility measurement of the trunk in the hands nape-neck position was performed in accordance with the protocol (Miller, 2006).

Motor Measurements and Tests: In the research, measurements for vertical jump and handgrip strength were taken with three repetitions and in accordance with the protocol. Warm-up exercises were performed before conducting the motor measurement and tests. The T 2000 test was recorded in minutes using a digital stopwatch in a 50-meter competition pool. A goniometer was used for the flexibility measurement (Miller, 2006). The 400 meters' freestyle swimming time during the 2022-2023 Winter Season long course competition period was recorded in minutes and seconds, using an electronic scoreboard in a 50 m competition pool, in accordance with FINA competition rules. During performance measurements, participants were audibly motivated to ensure maximum efficiency.

Data analysis

The statistical analyses of the data obtained in our study were conducted using the SPSS software (Version 22.0, SPSS Inc., Chicago, IL, USA, License: Hitit University). Descriptive statistics for continuous variables were presented as mean ± standard deviation, and for categorical data as number and percentage. The analysis of the data was done independently for two different age groups. The Shapiro-Wilk test was used to determine the normality distribution of statistical data. For continuous variables, the Student-t test was used for data showing normal distribution, and the Mann-Whitney U test was used for data not showing normal distribution, to compare independent two groups. Each data set with 400 meters' freestyle measurements was considered as a dependent variable. The linear relationships between the measurement and test findings and the 400 meters swimming performance variables were evaluated with the Pearson correlation coefficient. Simple linear regression analysis was performed to predict the effects of independent variables (anthropometric and motor skills) on the de-pendent variable (four hundred meters' freestyle swimming style). Variables showing significant results in r2 were taken in regression models for four hundred meters swimming style according to correlation analysis results. All statistical procedures were performed separately for each age group, and statistical significance was accepted at a confidence level of $p<0.05$.

FINDINGS

In this study, no participant was excluded due to injury, illness, or disinterest, thus all swimmers were included in the final analyses. The physical and anthropometric descriptive measurement findings for the subjects, who were divided into two groups, are presented in Table 1.

Table 1. Descriptive and anthropometric characteristics of participants

	12 – 13 (age) n=20		14 – 15 (age) n=20		Difference (%)	p
	x̄ ± Sd	Median Min - Max	x̄ ± Sd	Median Min - Max		
Age (year)	12.50±0.51	12.5(12-13)	14.35±0.48	14(14-15)	14.8	0.000*
Height (cm)	161.60±9.98	159.5(143-175)	169.8±6.53	169(159-182)	-1.29	0.011*
BW (kg)	52.48±7.17	55.55(39.5-61)	61.45±8.88	63.85(46.40-78.20)	17.09	0.003*
BF (%)	8.25±3.61	8.09(3.72-15.40)	5.76±1.06	5.80(3.99-7.80)	-30.18	0.028*
LBM (kg)	48.08±6.45	48.28(36.77-55.87)	57.94±8.66	60.47(43.71-73.16)	20.50	0.001*
SE (year)	3.95±0.82	5 (4-6)	5.35±1.22	6 (4-8)	35.4	0.001*

*=p<0.05; LBM: Lean Body Mass; BF%: Body Fat Percentage; BW: Body Weight; SE: Sports Experience

As seen in Table 1, there are statistically significant difference between the groups in terms of age, height, BW, BF, LBM, and SE ($p<0.05$).

Table 2. Diameter and circumference measurements of participants.

	12 – 13 age		14 – 15 Age		Difference (%)	p
	x̄ ± Sd	Median Min - Max	x̄ ± Sd	Median Min - Max		
Upper Body Length (cm)	81.51±5.98	82.5(71-92)	86.25±6.32	83.15(79-89)	5.81	0.060
Leg Length (cm)	80.10±5.19	80(70.80-87)	83.69±2.99	83(79-89)	4.48	0.035*
Single Arm Length (cm)	68.31±4.92	66.65(60-75)	71.34±3.35	70.90(65.5-77)	4.43	0.040*
Biceps Circumference (cm)	24.34±1.83	24.5(20.5-27)	24.77±1.83	24.5(22-28)	1.76	0.547
Shoulder Diameter (cm)	29.99±2.80	30(26-36)	31.55±2.18	32(28-35)	5.20	0.043*
Pelvis Diameter (cm)	25.88±2.18	36.35(22.10-29)	26.93±2.92	27(22-32)	4.05	0.314
Elbow Diameter (cm)	7.41±0.93	7.40(5.90-8.80)	7.65±1.25	8.2(6-9.40)	3.23	0.289
Knee Diameter (cm)	9.18±0.77	9.15(7.70-10.60)	9.84±0.77	9.80(8.40-11)	7.18	0.024*

As observed in Table 2, there are statistically significant difference between the groups in terms of leg length, single arm length, shoulder diameter, and knee diameters ($p<0.05$).

Table 3. Flexibility and motor measurement results of the participants.

	12 – 13 age		14 – 15 age		Difference (%)	p
	x̄ ± Sd	Median Min - Max	x̄ ± Sd	Median Min – Max		
400 Meter Freestyle	5.58±0. 52	5.42 (4.55-6.35)	5.01±0.28	5.10 (4.40-5.45)	-10.21	0.000*
Vertical Jump Test (cm)	31.45±4.94	30.50 (25-42)	38.90±5.69	38 (31-48)	23.68	0.000*
Hand Grip (kg)	25.22±5.00	27.70 (16.60-31)	35.35±6.93	36.20 (25.80-47)	40.16	0.000*
Trunk Flexibility at Arm's Length (cm)	48.85±8.83	50.50 (30-64)	57.60±7.78	55 (45-71)	17.91	0.005*
Aerobic Endurance (min)	31.03±2.63	30.10 (27.10-36.25)	28.64±1.94	29.06 (26.01-33.10)	-7.70	0.004*

*p<0.05

According to Table 3, there are statistically significant difference between the groups in terms of 400 meters' freestyle, vertical jump, handgrip, trunk flexibility in hand crossed nape-neck position, and aerobic endurance test values ($p<0.05$).

Table 4. Regression analysis results for four hundred meters' freestyle for ages 12 – 13

Model	Regression Coefficients		Standardized Coefficients	t	p	95% Confidence Interval for B		R^2	ANOVA
	B	Standard Error	Beta			Lower Bound	Upper Bound		
Constant	9.178	1.011		9.074	0.000	7.053	11.303	0.414	F(1.18)=12.72
Shoulder Diameter	-0.120	0.034	-0.643	-3.566	0.002	-0.190	-0.049		
Constant	7.220	0.495		14.581	0.000	6.180	8.260	0.386	F(1.18)=11.30
Hand Grip	-0.065	0.019	-0.621	-3.361	0.003	-0.105	-0.024		
Constant	7.085	0.590		12.009	0.000	5.845	8.324	0.270	F(1.18)=6.66
Flexibility at Arm's Length	-0.031	0.012	-0.520	-2.580	0.019	-0.056	-0.006		
Constant	2.085	1.196		1.744	0.098	-0.427	4.597	0.324	F(1.18)=8.63
Aerobic Endurance	0.113	0.038	0.569	2.938	0.009	0.032	0.193		

According to the results of the regression analysis among the correlated variables, it has been observed that a 5 centimeter increase in shoulder diameter will cause a 0.5 second decrease in the four hundred meters' freestyle time. According to the adjusted R^2 value, 41.4% of the fifty meters' freestyle time is explained by the shoulder diameter ($p<0.001$; Table 4). An 8-kilogram increase in handgrip strength is seen to cause a 0.5 second decrease in the four hundred meters' freestyle time. According to the adjusted R^2 value, 38.6% of the fifty meters' freestyle time is explained by handgrip strength (p<0.001; Table 5). A 16 centimeter increase in trunk flexibility in nape-neck position will result in a 0.5 second decrease in the four hundred meters' freestyle time. According to the adjusted R^2 value, 27% of the four hundred meters' freestyle time is explained by trunk flexibility in nape-neck position (p<0.001; Table 4). A 500-meter increase in aerobic endurance will cause a 0.5 second decrease in the four hundred meters' freestyle time. According to the adjusted R^2 value, 32.4% of the four hundred meters' freestyle time is explained by trunk flexibility in nape-neck position (p<0.001; Table 4).

Table 5. Regression analysis results for four hundred meters' freestyle for ages 12 – 13

Model	Regression Coefficients		Standardized Coefficients	t	P-value	95% Confidence Interval for B		R^2	ANOVA
	B	Standard Error	Beta			Lower Bound	Upper Bound		
Constant	6.200	0.369		16.809	0.000	5.425	6.975	0.369	F(1.18)=10.52
Body Weight	-0.019	0.006	-0.607	-3.243	0.005	-0.032	-0.007		
Constant	10.522	1.139		9.239	0.000	8.130	12.915	0.565	F(1.18)=23.41
Upper Body Length	-0.040	0.005	-0.887	-8.129	0.000	-0.050	-0.029		
Constant	9.550	0.924		10.336	0.000	7.609	11.491	0.573	F(1.18)=24.14
Biceps Flexion Circumference	-0.094	0.029	-0.613	-3.291	0.004	-0.155	-0.034		
Constant	7.562	0.751		10.074	0.000	5.985	9.139	0.391	F(1.18)=11.56
Pelvis Diameter	-0.072	0.015	-0.751	-4.822	0.000	-0.104	-0.041		
Constant	6.380	0.248		25.749	0.000	5.860	6.901	0.634	F(1.18)=31.11
Elbow Diameter	-0.178	0.032	-0.796	-5.578	0.000	-0.245	-0.111		
Constant	8.102	0.422		19.201	0.000	7.215	8.988	0.749	F(1.18)=53.82
Knee Diameter	-0.314	0.043	-0.866	-7.336	0.000	-0.403	-0.224		
Constant	6.708	0.219		30.627	0.000	6.248	7.169	0.772	F(1.18)=60.95
Vertical Jump	-0.044	0.006	-0.879	-7.807	0.000	-0.055	-0.032		
Constant	6.200	0.195		31.755	0.000	5.790	6.610	0.679	F(1.18)=38.14
Hand Grip	-0.034	0.005	-0.824	-6.176	0.000	-0.045	-0.022		
Constant	6.894	0.216		31.877	0.000	6.439	7.348	0.810	F(1.18)=76.74
Flexibility at Arm's Length	-0.033	0.004	-0.900	-8.760	0.000	-0.040	-0.025		
Constant	1.247	0.415		3.008	0.008	0.376	2.119	0.822	F(1.18)=82.92
Aerobic Endurance	0.132	0.014	0.906	9.106	0.000	0.101	0.162		

According to the results of the regression analysis among the correlated variables; a decrease of 10 kilograms in body weight will result in a 0.25-second decrease in the four hundred meters' freestyle time. According to the adjusted R2 value, 36.9% of the fifty meters' freestyle time is explained by body weight (p<0.001; Table 5). A 12 centimeter increase in upper body length is seen to cause a 0.5-second decrease in the four hundred meters' freestyle time. According to the adjusted R2 value, 56.5% of the fifty meters' freestyle time is explained by upper body length (p<0.001; Table 5). A 5 centimeter increase in biceps flexion circumference will result in a 0.5-second decrease in the four hundred meters' freestyle time. According to the adjusted R2 value, 56.5% of the fifty meters' freestyle time is explained by biceps flexion circumference (p<0.001; Table 6). A 7 centimeter increase in pelvis diameter is seen to cause a 0.5-second decrease in the four hundred meters' freestyle time. According to the adjusted R2 value, 39.1% of the fifty meters' freestyle time is explained by pelvis diameter (p<0.001; Table 5). A 3 centimeter increase in elbow diameter will result in a 0.5-second decrease in the four hundred meters' freestyle time. According to the adjusted R2 value, 63.4% of the fifty meters' freestyle time is explained by elbow diameter (p<0.001; Table 5). A 2 centimeter increase in knee diameter is seen to cause a 0.5-second decrease in the four hundred meters' freestyle time. According to the adjusted R2 value, 74.9% of the fifty meters' freestyle time is explained by knee diameter (p<0.001; Table 5). A 10 centimeter increase in vertical jump will result in a 0.5-second decrease in the four hundred meters' freestyle time. According to the adjusted R2 value, 77.2% of the fifty meters' freestyle time is explained by vertical jump (p<0.001; Table 5). An 8-kilogram increase in handgrip strength is seen to cause a 0.5-second decrease in the four hundred meters' freestyle time. According to the adjusted R2 value, 67.9% of the fifty meters' freestyle time is explained by handgrip strength (p<0.001; Table 5). A 15 centimeter increase in trunk flexibility in nape-neck position will result in a 0.5-second decrease in the four hundred meters' freestyle time. According to the adjusted R2 value, 81% of the four hundred meters' freestyle time is explained by trunk flexibility in nape-neck position (p<0.001; Table 5). A 400-meter increase in aerobic endurance is seen to cause a 0.5-second decrease in the four hundred meters' freestyle time. According to the adjusted R2 value, 82.2% of the four hundred meters' freestyle time is explained by trunk flexibility in nape-neck position (p<0.001; Table 5).

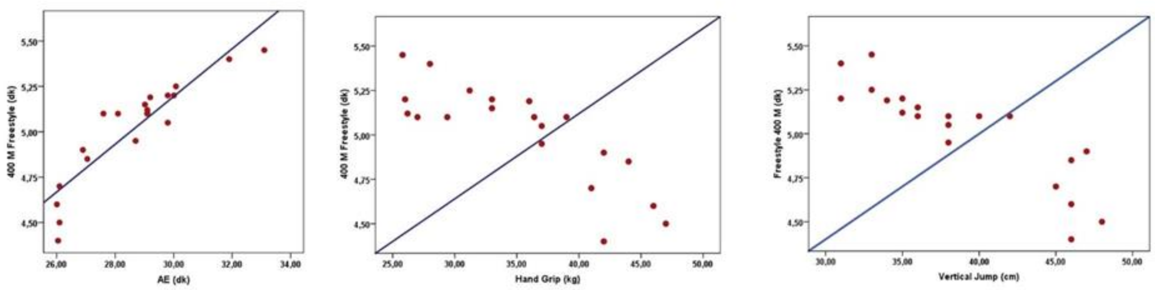

Figure 1. 14 – 15 years with very high correlation measurement

DISCUSSION AND CONCLUSION

In this study, certain anthropometric and motor characteristics of young swimmers in two different age groups were examined, and their relationships with 400 m freestyle swimming performance were analyzed.

According to the results of the study, there is a positive correlation between anaerobic endurance and 400 m free time, while there is a negative correlation between handgrip strength and 400 m free time. This suggests that as anaerobic endurance increases, 400m free time increases, whereas as grip strength increases, 400m free time decreases. When examining anthropometric data according to age groups, significant differences were found in leg length, single arm length, shoulder diameter, and knee diameters between the two age groups, but no differences were observed in upper body length, biceps circumference, pelvis diameter and, elbow diameter (Table 2). These results suggest the presence of growth and changes with age in measured anthropometric parameters among them naturally. Reviewing the literature, Şeyma and Saygın (2019) reported in their study that an increase in swimmers' upper body length correlates with better performance in 50 m freestyle swimming (İnan & Saygın, 2019). Biceps circumference, shoulder diameter, pelvis diameter, elbow diameter and knee diameters are seen as effective parameters' in 400 m swimming performance in our study (Table 2). Similarly, in a literature review, Peters, Berry, and Koley (2014) found that increases in diameters' and circumferences contribute positively to strength development and swimming performance in 50 m freestyle swimming (Peters, et al., 2014). Rozi et al. (2018) reported that triceps, pelvis, and shoulder diameters' have an impact on the 100 m freestyle swimming performance of elite swimmers (Rozi, et al., 2018). However, Fiori et al., (2022) concluded in their study that performance and kinematic variables were more significant than anthropometric measurements in swimmers aged twelve and younger (Fiori, et al., 2022). The results obtained from these studies support the findings of our study.

When examining performance findings according to age groups, it is observed that endurance (T2000), anaerobic power (vertical jump), strength (hand grip), and flexibility (trunk-neck) performances are significantly higher in the 14-15 age group (Table 3). Additionally, athletes in the 14-15 age group were found to complete the 400-meter swimming distance in a significantly shorter time (Table 3), with a significance level of ($p>0.05$). Literature studies reveal that Demirkan et al. (2023) in their research, indicated significant differences in aerobic endurance between age groups and swimming styles. They also reported significant differences in anaerobic power (vertical jump), strength (hand grip), and flexibility (trunk-neck and ankle) performance measurements across age groups (Demirkan, et al., 2023). Mitchell et al. (2018) in their study, indicated that loaded and unloaded jump heights have an explanatory effect on 200 m freestyle swimming performance (Bond, et al., 2014). Our study shows that hand grip strength is an effective strength parameter for 400 m freestyle swimming performance; literature review reveals that Mitchell et al. (2018) reported the effectiveness of strength in 100 m freestyle swimming performance. Our study observes that ankle dorsiflexion flexibility of the right ankle is an effective parameter on 400 m freestyle swimming performance; literature review indicates that Willems et al. (2014) found a positive correlation between ankle flexibility and dolphin kick, positively affecting muscle strength and thereby enhancing swimming performance (Bond, et al., 2014) (Willems et al., 2014). Our study demonstrates that T2000 m swimming aerobic capacity is effective in 400 m swimming distances in both groups. Literature review shows that Kalva-Filho et al. (2015) reported the effectiveness of aerobic capacity in 400 m freestyle swimming performance (Kalva-Filho et al., 2015). Mitchell et al. (2018) in their study, indicated the explanatory effect of aerobic capacity in 100 m performance (Mitchell et al., 2018).

In our study on swimming related to the 12-13 age group, factors emerging in the regression model and their impact on performance have been correlated with the literature.

In our study, shoulder width (r2=0.414) has a high correlation with actual competition performance, showed that providing a wider pull area and power during swimming, which aids in more effective propulsion of water. In the 12-13 age group, shoulder width is a significant factor that can directly affect swimming speed (Maglischo, 2012; Kalva-Filho, et al., 2015; Özkadı, et al., 2022). Hand grip strength (r2=0.386); a strong hand grip increases the capacity to effectively catch and push the water. Our study also showed that, the impact of grip strength on swimming speed in this age group is an indicator combining technical skill and power development (Nikšić, et al., 2008; Zampagni, et al., 2008; Özkadı, et al., 2022). Flexibility in hand length (r2=0.270); flexibility allows swimmers to have a wider range of motion, enabling more distance to be covered in each stroke. The relationship in this age group's study is consistent with the literature (Hall, et al., 2012; Maglischo, 2012; Beattie, et al., 2014; Morais, et al., 2021; Reichmuth, et al., 2021). Aerobic endurance (r^2=0.324), due to swimming being an aerobic sport, the aerobic capacity of swimmers in this age group is one of the most important factors determining sustainable speed over long distances, such as 400 meters'. The highest correlation in this study was obtained in the aerobic test result (Hall, et al., 2012; Maglischo, 2012; Kachaunov and Petrov, 2020; Morais, et al., 2021). It is understood and confirmed with literature that aerobic capacity is highly effective and significant in this age group. This study identifies that factors such as shoulder width, flexibility, and hand grip strength have a direct impact on swimming speed in the 12-13 age group. These findings play a crucial role in designing training programs focused on the technical and physical development of young swimmers.

When examining the findings of the study for the 14-15 age group and the determinative factors and their effects in the regression model along with literature; Also in this age group, it is observed that body weight (r2=0.369), and upper body length (r2=0.565) have a significant impact on swimming performance (Table 6). A longer upper body implies a longer stroke length, while body weight can enhance balance and hydrodynamic efficiency in water (Hall, et al., 2012; Maglischo, 2012; Zampagni, et al., 2012; Tabaki, et al., 2016; Marinho, et al., 2021).

The group's biceps flexion circumference (r^2=0.573), pelvis width (r^2=0.391), elbow diameter (r^2=0.634), and knee diameter (r^2=0.749) measurement results and regression model correlations were found to be high. This finding is significant as stronger biceps muscles assist in more effective propulsion of water, while the diameters' of the pelvis, elbow, and knee can affect the body's balance and movement efficiency during swimming (Hall, et al., 2012; Maglischo, 2012; Zampagni, et al., 2012; Lima-Borges, et al., 2022). In our study, values found to be highly correlated such as vertical jump (r^2=0.772), hand grip (r^2=0.679), flexibility in hand length (r^2=0.810), and aerobic endurance (r^2=0.822) (Table 6) indicate that in this age group, as with younger swimmers, explosive power (vertical jump), and grip strength are important factors alongside flexibility and aerobic capacity (Hall, et al., 2012; Maglischo, 2012; Zampagni, et al., 2012; Seffrin, et al., 2021). These findings suggest that in 14-15-year-old swimmers, factors such as body weight and upper body length have a distinct impact on performance. In this age group, it has been found that arm and shoulder strength, leg jumping power, and aerobic capacity, similar to younger swimmers, have a significant impact on performance.

This study, particularly focused on children and adolescent swimmers, utilizes regression models to analyze and correlate long distance performances in freestyle swimming, such as 400 meters', which emerges as a relatively new and under-researched area in literature. Most studies in this field have focused on short distance races, such as 50 and 100 meters' (Zampagni, et al., 2008; Morais, et al., 2017). This indicates a significant potential area for developing data analysis and modeling techniques for predicting and improving long distance swimming performance. Our literature review revealed that similarly to us, Sefrin and colleagues found in their regression modeling of 100 and 400 m freestyle swimming performances a clear correlation between age and 100 m performance (r^2=0.51) and between age and 400 m performance (r^2=0.34) in the 11-12 age group.

For the 13-14 age group, they indicated that lean body mass, muscle strength, and anthropometric parameters' contributed to in the statistical model, with lean body mass, muscle strength, and trunk width being explanatory for 100 m performance (r^2=0.83) and muscle strength together with lower extremity length for 400 m performance (r^2=0.57) (Seffrin, et al., 2021).

In a comprehensive study similar to ours, Zampagni et al. (2008), evaluated factors such as age, body mass, height, arm length, forearm length, forearm muscle volume, and hand grip strength in freestyle swimming distances; they noted that while age, height, and hand grip strength were the best determinants for short distances, only age and height were determinative for medium and long distances. They reported the relevant determination coefficients as r^2=0.84 for 50 m, r^2=0.73 for 100 m, r^2=0.75 for 200 m, r^2=0.66 for 400 m, and r^2=0.63 for 800 m races (Zampagni, et al., 2008).

The primary aim of this study was to correlate and analyze the interaction between the 400-meter swimming performance, a key indicator of endurance, and various motor and anthropometric characteristics for children and young swimmers.

In this study, the 400-meter freestyle performance of young swimmers, along with their physical and motor characteristics, were investigated through regression analyses on two groups within the 12-15 age range. It was demonstrated that both athletic performance and motor test performances increase and are influenced by together with the age progression and sports experience. In the 12-13 age group, metrics such as shoulder width, hand grip strength, flexibility in hand length, and aerobic endurance emerged as dominant factors affecting real competition performance, while in the 14-15 age group, aerobic endurance, body weight, upper body length, muscle strength, circumferential measurements (biceps flexion circumference, pelvis diameter, elbow diameter, knee diameter), and motor skills (vertical jump) were more determinative.

Recommendations

From these findings, it is understood that coaches and related professionals need to focus on shoulder and arm development in the early age group (12-13), as this can help swimmers create a wider pull area on the water surface, thereby potentially increasing their speed. The importance of flexibility and aerobic endurance training for this age group is also evident from the findings.

In the 14-15 age group, in addition to other tested factors, it was observed that elements such as body weight and upper body length became more prominent. Training programs for swimmers in this young group should concentrate on optimizing the body composition, enhancing aerobic endurance, increasing muscle strength, and developing explosive power.

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