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ORIGINAL

ARTISTIC SWIMMING IN GIRLS: ANTHROPOMETRICS, GENOTYPE AND ATHLETIC PERFORMANCE

NATACIÓN ARTÍSTICA EN NIÑAS: ANTROPOMETRÍA, GENOTIPO Y RENDIMIENTO DEPORTIVO

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ABSTRACT

In sport, optimizing weight and body composition is important for performance although an excessive drive for thinness can lead to diminished performance and health problems. This is especially important in the youngest athletes.

This study examines 60 national competition-level Spanish artistic swimmers aged 9-17 years. Participants were divided into 3 categories: 12 years and under, 13-15 and 16-17 years. The data analysed were anthropometric measures, menarche age, genotype related to performance (gene *ACTN3)* and athletic performance. Relationships between athletic performance and anthropometric or genetic data were compared among the three age groups.

Swimmers showed a tendency to carry the heterozygous genotype RX of the *ACTN3* gene in the older age group. In this study, this sport could have an impact on body mass index, triceps skinfold, weight, menarche age, and selection of one genotype, but the performance in competition of the artistic swimmers had little linking to anthropometric measures.

KEYWORDS: *ACTN3* gene; anthropometric measures; synchronized swimming; youth.

RESUMEN

En cada deporte es importante optimizar peso y composición corporal y la genética y los datos antropométricos pueden influir en rendimiento deportivo y salud, sobre todo en deportistas menores.

Este estudio analiza 60 nadadoras artísticas entre 9 y 17 años, divididas en tres grupos de edad: ≤12, 13-15 y 16-17 años. Se realizó un análisis de medidas antropométricas, edad de menarquia, genotipo relacionado con rendimiento (gen *ACTN3*) y resultados deportivos, con objetivo de relacionar estos parámetros entre sí en los grupos de edad.

Las nadadoras de mayor edad mostraron tendencia a portar el genotipo heterocigoto RX de *ACTN3*. En este estudio, la práctica de este deporte podría tener impacto en índice de masa corporal, pliegue tricipital, peso y edad de menarquia. La mayor prevalencia del genotipo heterocigoto *ACTN3* R577X podría ofrecer una ventaja, pero el rendimiento en competición de las nadadoras artísticas tuvo poca relación con sus medidas antropométricas.

PALABRAS CLAVE: Gen *ACTN3*, medidas antropométricas, natación sincronizada, infancia.

INTRODUCTION

Several studies claim the existence of an ideal weight and body composition for successful performance in every sport (1). Artistic swimming (AS, former synchronized swimming) has physical requirements that makes it a unique sport (2). Body shape is not a scored element, but it is a focus for coaches and swimmers. This added to the high training volume needed for AS means the nutritional demands of artistic swimmers are complex and there is some evidence that practitioners of aesthetic sports have a higher risk of relative energy deficiency in sport (RED-S, 3).

To date, many research efforts have looked for a direct relationship between genetics and sport. These investigations have examined the influence of an athlete's genetic profile on performance and tried to identify an optimal genotype for physical exercise (4). It has been described, for example, the influence of the α-actinin-3 gene, *ACTN3*, in some speed and power-oriented sports (5). In effect, a strong relationship has been established between *ACTN3* R577X genotype and training adaptation. α-actinin-3 plays a major role in stabilizing the contractile apparatus, it is almost exclusively expressed in skeletal muscle fast-twitch fibres (type II) and it produces powerful contractions (6). A link between genotype *ACTN3* RR and performance in power sports has been described, especially in women (5, 7), whereby R allele could have beneficial effects on athletic performance in speed and power tests. Accordingly, the R allele is more frequently found in athletes specialized in speed and power sports, while null allele X and genotype XX, in which ACTN3 is lacking, are slightly more frequent in endurance athletes and are underrepresented in speed and power sports (8). No correlation was observed between the *ACTN3* R577X polymorphism and an elite status among Spanish swimmers (9). To date, no study has examined this gene in artistic swimming, classified as a power sport due the duration and nature of the exercises. Because AS is a minority sport, data on this topic are scarce in comparison with other sports, and the few existing studies have examined small populations of usually elite adult athletes (10-13). Information related to girls practicing sports is even more rare (14, 15) and data about minor Spanish artistic swimmers are very few (16).

The present study was designed with the general objective of determining if anthropometric data and/or genetic factors affect the performance of minor Spanish artistic swimmers. To this end, we collected a set of anthropometric data in 60 minor artistic swimmers of competition level among 9 and 17 years old, the results of physical tests and figures competitions and *ACTN3* genetic test was performed.

The specific objectives were: to find out if practising AS has an effect over the anthropometric data in minors, if a determined body shape is associated with a better performance in AS, and if there is a higher prevalence of the *ACTN3R* allele, more frequent in power sports, in swimmers showing better performance.

MATERIALS AND METHODS

PARTICIPANTS

Participants were 60 girls from 9 to 17 years old with at least 2 years of experience in AS, who were members of one of three clubs the Madrid Community that competed at the national level (representing 70.6% of all girl artistic swimmers of that level in Madrid during 2016-17 season). Written informed consent was first obtained from parents and also from participants when they were older than 12 years. The study was approved by the Ethics Committee of the *Comunidad de Madrid*. Participants were divided as follows into the 3 age categories defined by the International Federation of Swimming (FINA): 12 years and under (15 artistic swimmers, aged 10.65 ±1.03 years, mean ±SD); 13-15 years (31 swimmers aged 13.68 ±0.83 years); and 16-18 years (14 swimmers, aged 16.24 ±0.91 years). The average hours of training per week in each age group were 14-18, 15-20, and 15-24, respectively, depending on the season time and the level of the swimmers.

The sample size needed in each group of participants was calculated to detect a significant difference in average performance scores. This calculation was based on a confidence level of 95%, a minimum power of the study of 90%, a minimum difference detected of 5 points in this score and a standard deviation of 2.18. The required number of individuals in each age group was 6.

ANTHROPOMETRIC DATA

In all participants, the following measurements were made: height, weight, triceps skinfold, and body fat percentage using a bioelectrical impedance weighing machine TANITA (Segmental Body Composition Monitor InnerScanV, model BC-545N). Body mass index (BMI) was categorized into the 5 classes defined by Carrascosa *et al*. (17) as recommended by Sánchez González *et al*. (18; undernourished, UN, risk of undernourishment, thin, normal, overweight). Participants were asked about the number of years they had been practicing AS at the competition level and their date of menarche.

GENETIC TESTING

A sample of epithelium was collected from the mouth with a swab and DNA was purified using the QiAmp DNA blood mini kit (Qiagen).
ACTN3 R577X (rs1815739) genotyping was performed by qPCR using the following primers: F 5'-CAGCGCACGATCAGTTC and R 5'-CCCTGGATGCCCATGA and the probes 5'-CCTCGCTCTCGGTCAGCCTC (R allele) labelled with FAM and 5'-CCTCGCTCTCAGTCAGCCTC (X allele) labelled with HEX. The 20 µL reaction mix consisted of 10 µL Sso Advance Universal SyBr Green supermix (BioRad), 0.5 µM each primer, 0.2 µM each probe and 100 ng DNA. The PCR conditions were 98ºC 2 min, 49 cycles at 98ºC 10 s, 67ºC 20 s and a final extension at 72ºC 5 min.

ATHLETIC PERFORMANCE

Performance in the swimmers was assessed through physical tests (medicine ball throw, 25 m swim and boost) and through individual figures competition scores. These physical tests were selected as the girls had experience with them as part of the *Real Federación Española de Natación* (Spanish Swimming Federation) programme (https://rfen.es/es/section/niveles).

MEDICINE BALL THROW

Each swimmer was asked to throw the ball (1 kg, 62 cm perimeter, Tremblay CT, Gleizé, France) twice in a row and only the longest of the two distances was recorded. The throw was started at a line marked on the ground with feet together and legs extended. The ball was then thrown as far as possible moving the arms above the head from back to front as indicated by the *Real Federación Española de Natación*. If the swimmer did not adopt the correct throwing position or stepped over the starting line, the throw was considered null and repeated. Swimmers had a couple of practice trials before the test. A 20-m tape attached to the floor at the starting line was used to measure the throw distance perpendicular to the launching point. Before each throw, the ball was submerged in magnesium (MgCrunchy) to mark the spot where the ball first touches the floor. The throw distance was measured from the measuring tape attachment point to the middle of the mark left by the ball.

25 M FRONT CRAWL SWIMMING

The test was performed in a 25 m-swimming pool. Each swimmer swam the pool length front crawl style as fast as possible, starting from the pool kerb. Once in the starting position, the test start was indicated with a clap and then "ready, steady, go". The test was recorded from the arrival point with a digital hybrid camcorder (JVC Everio HDD, model GZ-MG135E, 34x optical zoom, 720p resolution, JVCKenwood, USA). The test finish was when the swimmer touched the swimming pool wall. The test time was calculated using the image analysis software package Kinovea 0.8.15 (Kinovea.org).

Adequate intraobserver and interobserver reliability were confirmed by comparing the times recorded by one observer and then independently by two further observers respectively.

BOOST

The test was performed in 25 m-length, at least 2 m-deep-swimming pools. Each swimmer was asked to perform a boost, regular figure in AS, in the final row and in the deepest part of the pool. The initial position in the Boost was set in the submerged head of the swimmer and she moved upward as highest as possible with the arms attached to the body, without touching the wall nor the floor of the swimming pool in any moment (Figure 1). Each swimmer performed two attempts and the best result was kept for further studies.

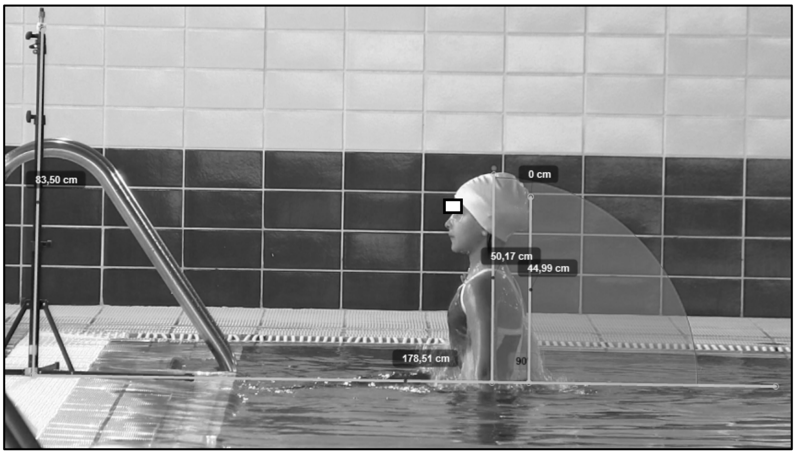


Figure 1: Measurement of Boost test

Reference for analyses were a red point on the floor of the swimming pool and a pole situated on the pool kerb (Figure 1). The test was recorded by an observer with a digital hybrid camcorder (JVC Everio HDD, model GZ-MG135E, 34x optical zoom, 720p resolution, JVCKenwood, USA) while another observer controlled the correct position of the swimmer.

The height of the Boost was calculated using the image analysis software package Kinovea 0.8.15 (Kinovea.org); the start point was the upper part of the head breaking the water surface and the finish point was the height of the head before the descent. Adequate intraobserver and interobserver reliability were confirmed by comparing the times recorded by one observer and then independently by two further observers respectively. For statistical analyses, the result of the Boost was normalized for the swimmer's height by dividing this data.

FIGURES COMPETITION SCORES

Scores for each swimmer were obtained from the *Real Federación Española de Natación* and *Federación Madrileña de Natación* (Madrid Swimming Federation,) websites (https://rfen.es/es/section/natacion-artistica-resultados and http://www.fmn.es/mar13/competicion_si.asp?Area=CZ) as the average figure scores obtained in the last four official competitions (seasons 2015-16 and 2016-17).

DATA ANALYSIS

Quantitative variables are provided as medians and their interquartile ranges (IQR) or as the mean ± standard deviation (SD) depending on their distribution (Shapiro-Wilk test for normality). Qualitative variables are expressed as absolute and relative frequencies in percentages. The chi-squared test was used to analyze qualitative variables. The Student's t- test or Mann–Whitney U Test were employed, as appropriate, to compare quantitative variables. Spearman correlation coefficients were calculated to assess relationships between physical tests and competition scores, anthropometric measures and athletic performance (physical tests and competition scores) and genotypes and athletic performance.

All statistical tests were performed using the software package Stata IC, v. 14 (StataCorp LLC., Texas USA). Significance was set at $p < 0.05$.

RESULTS

The anthropometric measurements obtained in the artistic swimmers are provided in Table 1. Menarche age in the youngest age group was not considered, because none of them was in menarche. None of the girls was classified in the overweight group and significant differences in BMI classifications among age groups were not observed. BMI distribution did not correlate with data published for general population by World Health Organization that describes 22% overweight in 9-year old girls (19), and by Yáñez-Ortega *et al*. (20), that detected 18.5% overweight in 14-year old girls.

Table 1: Anthropometric data in age group swimmers. Data are expressed as mean ±standard deviation or absolute and relative frequencies. SN: subnutrition.

DATA	12 YEARS and UNDER (n=15)	13-15 YEARS OLD (n=31)	16-17 YEARS OLD (n=14)
Height (cm)	144.73 ±5.80	157.54 ±6.50	163.12 ±6.93
Weight (Kg)	34.91 ±6.35	47.13 ±7.17	53.19 ±6.10
Body mass index (BMI)	16.57 ±2.17	18.90 ±1.97	19.95 ±1.43
BMI class:			
SN, n (%)	2 (13.30)	0 (0.00)	0 (0.00)
SN risk, n (%)	1 (6.67)	2 (6.45)	1 (7.14)
Thinness, n (%)	6 (40.00)	11 (35.48)	5 (35.71)
Normal, n (%)	6 (40.00)	18 (58.06)	8 (57.14)
Overweight, n (%)	0 (0.00)	0 (0.00)	0 (0.00)
Body fat %	22.68 ±3.66	22.41 ±2.18	23.69 ±2.93
Triceps skinfold (mm)	13.42 ±5.43	11.83 ±3.23	12.81 ±3.68
Menarche age (years)	Without menarche	12.97 ±0.93	14.05 ±1.15

The results of genotyping of *ACTN3* gen are shown in Figure 2. Genotypes RR, RX and XX distribution among the different age groups were statistically significant (p<0.001), with an increased percentage of RX genotype in the older group of swimmers.

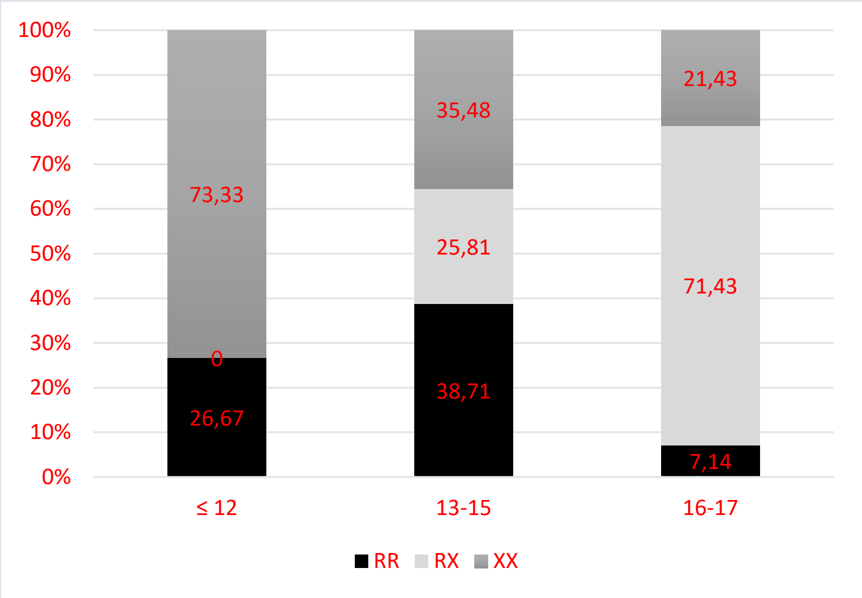


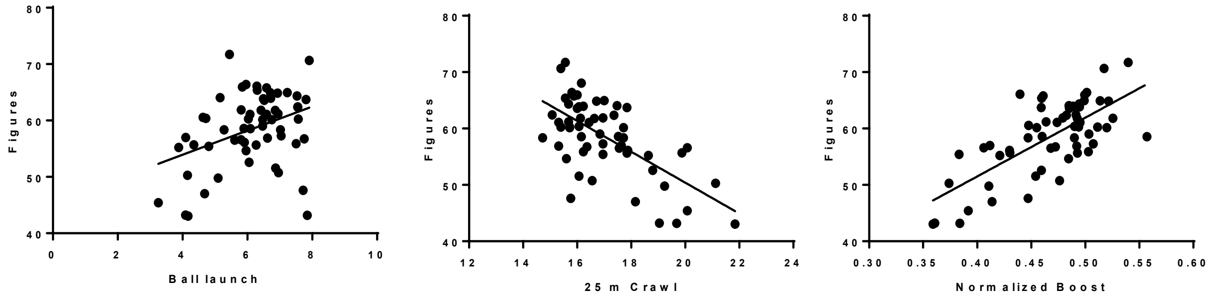
Figure 2: Percentages of prevalence of *ACTN3* genotypes in the different age groups. $p<0.001$.

The statistical study about correlations between *ACTN3* genotype and athletic performance did not reveal any significance, considering each genotype (RR, RX or XX) nor RR genotype *vs* RX and XX, with any of the physical tests or figure scores (data not shown).

In order to corroborate if the physical tests performed to the girls are predictor of their sport performance, statistical correlation among them and the results in figures official competitions was performed. In Table 2 it is shown a weak correlation but significant in the case of the ball launch, moderate in the case of 25 crawl test (negative correlation), where less time indicated better performance, and strong in the Boost test with the figures scores in the total of swimmers group (Table 2 and Figure 3). These results indicate that the physical tests performed by the swimmers are good indicators of their performance in AS.

Table 2: Statistical correlations between Figures scores and physical tests. Spearman correlation coefficients and 95% CI are indicated. Statistically significant correlations between variables: * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Age group/Test	Ball launch		25 m crawl		Normalized Boost	
Total swimmers	0.304*	(0.053, 0.520)	-0.541***	(-0.670, -0.330)	0.603***	(0.411, 0.744)
≤ 12	0.261	(-0.290, 0.682)	-0.583*	(-0.843, -0.100)	0.682**	(0.261, 0.885)
13-15	-0.033	(-0.389, 0.331)	-0.183	(-0.509, 0.190)	0.261	(-0.111, 0.567)
16-17	-0.331	(-0.733, 0.241)	-0.046	(-0.563, 0.497)	0.371	(-0.198, 0.191)



p<0,05 *p*<0,001 *p*<0,001

Figure 3: Graphical representation of the correlations between figures scores and physical tests in total swimmers group.

Correlations were assessed between the physical test results and anthropometric data (Table 3). Positive correlation was detected between some physical data and the ball-launch test results: percentage of body fat (weak or moderate correlation) and BMI (strong correlation) in the 13-15 years age group and the whole group of swimmers. A negative correlation was also found in the older group in the case of BMI and the Boost test, which turned to positive, but weak, in the case of the whole group.

Table 3: Statistical correlation between anthropometric data and physical tests and figure competition scores. Spearman correlation coefficients and 95% CI are indicated. Statistically significant correlations between variables: * *p*<0.05, ** *p*<0.01, *** *p*<0.001.

Item	Age group/Test	Ball launch		25 m Crawl		Normalized Boost		Figures	
Body fat %	Total	0.301*	(0.049, 0.517)	-0.034	(-0.288, 0.224)	0.039	(-0.0219, 0.292)	-0.014	(-0.267, 0.241)
	≤ 12	0.314	(-0.236, 0.712)	0.018	(-0.499, 0.525)	-0.132	(-0.604, 0.408)	-0.132	(-0.604, 0.408)
	13-15	0.529**	(0.208, 0.747)	-0.016	(-0.374, 0.346)	-0.128	(-0.466, 0.244)	-0.098	(-0.437, 0.266)
	16-17	-0.182	(-0.650, 0.385)	0.311	(-0.264, 0.722)	-0.284	(-0.708, 0.291)	-0.134	(-0.621, 0.427)
BMI	Total	0.658***	(0.483, 0.782)	-0.309	(-0.524, -0.058)	0.285*	(0.032, 0.505)	0,135	(-0.123, 0.376)
	≤ 12	0.321	(-0.228, 0.716)	-0.163	(-0.623, 0.381)	-0.004	(-0.515, 0.510)	-0.154	(-0.617, 0.389)
	13-15	0.703***	(0.460, 0.849)	-0.093	(-0.439, 0.276)	0.043	(-0.322, 0.397)	-0.259	(-0.562, 0.105)
	16-17	0.112	(-0.445, 0.607)	0.481	(-0.068, 0.805)	-0.701**	(-0.898, -0.272)	-0.367	(-0.751, 0.203)
Tricipital skinfold	Total	0.096	(-0.164, 0.344)	0.125	(-0.136, 0.370)	-0.050	(-0.303, 0.284)	-0.103	(-0.347, 0.156)
	≤ 12	0.079	(-0.452, 0.568)	0.009	(-0.506, 0.519)	-0.309	(-0.709, 0.241)	-0.331	(-0.721, 0.218)
	13-15	0.229	(-0.143, 0.544)	0.061	(-0.306, 0.412)	-0.046	(-0.400, 0.319)	-0.117	(-0.452, 0.248)
	16-17	-0.053	(-0.568, 0.491)	0.385	(-0.183, 0.760)	-0.181	(-0.649, 0.387)	-0.236	(-0.681, 0.337)

Figure 4 represents the correlations between BMI and boost test in the whole group of swimmers, groups ≤ 12 and 13-15 together (to corroborate the positive correlation with normalized boost) and the older group.

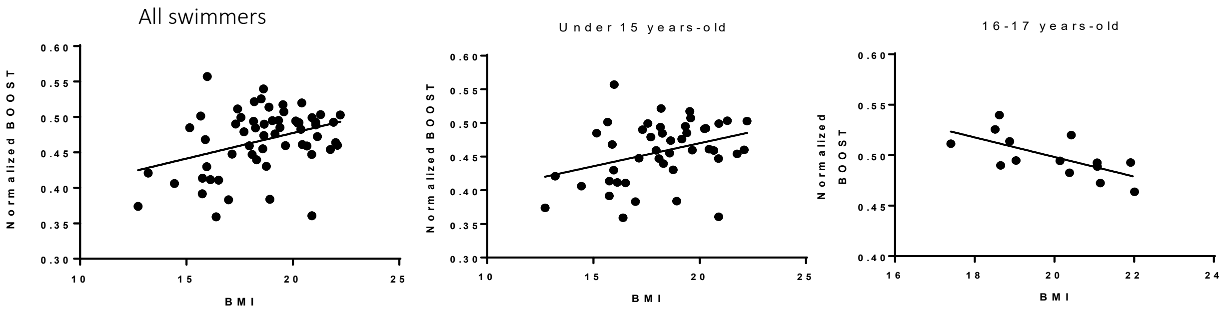


Figure 4: Graphical representation of the correlations in table 3 between results in normalized boost test and BMI in different age groups.

None significant correlation was found between anthropometric data and the figure competition scores (Table 3).

DISCUSSION

This study is a descriptive analysis of artistic swimmers aged between 9 and 17 years. Participants represented 70.6% of national competition-level artistic swimmers of the Madrid Community during season 2016-17. In Spain, AS is a minority sport. For example, over the season 2016-17, fewer than 700 girls under 18 years practised at the national level, though we should highlight that international results were excellent including third position in Free Combination at the European Junior Championship and first position in Free Team and Combination at the Mediterranean Cup in the category 13-15 years. This indicates that training was outstanding in quality and quantity in Spanish minor artistic swimmers.

Our anthropometric results indicate that AS had no association with height, as described by others (14), and the distribution among BMI categories are not changing significantly with the years of practising AS. This can be explained as an absence of selection of determined BMI categories or a selection in the first years of practising perpetuated during the age categories. A comparison of anthropometric data of swimmers with equivalent non-swimmers girls should be interesting in order to analyse the effect of this sport. In this issue, Zugno *et al*. analysed the rate of growth in artistic swimming girls and their data indicate a higher rate of increment of height and weight with respect to general population, although a delay in the peak of increment in height and weight is suggested (21), which can be related with the delay in menarche age and/or leanness prevalence determined in our study.

The anthropometric measurements in the oldest group of artistic swimmers were similar to those described for other junior Spanish AS swimmers (16, 22). Similar measurements were not described in youngest swimmers previously. The prevalence of leanness among swimmers has been associated with their reduced energy intake, especially during intensive training (23, 24). The difference between energy expenditure and intake may be related to the intense nature of the exercise, involving long periods of apnoea and with the athletes upside down. It is nevertheless true that leanness is a trait that coaches and the swimmers themselves strive for (3) and this could explain their low calorie intake. In effect, the lowest intake was recorded in swimmers showing a greater weight suggesting a drive for thinness in these girls (23).

A low body fat content observed in swimmers could be related to the delay in menarche observed (25). Other authors (26) have reported a delay of 0.6 years in AS compared to other sports, while we detected a delay of 1 year (13.40 *vs* 12.43) in comparison with data about general population in Spain (27). Regarding to genetic analysis, the older group of swimmers showed a 71.43% the RX genotype (α-actinin 3, Figure 2). These proportions were significantly different among age groups. Based on its short time routines involving explosive exercise actions, AS is considered a power sport, though long training times also mean a high resistance type of exercise. This would suggest that the heterozygous *ACTN3* RX genotype would represent an advantage in artistic swimmers, as hypothesized in swimming by others (28). These last authors were unable to detect a higher prevalence of this heterozygosity in Spanish elite non-artistic swimmers (9). Nevertheless, the results of the present study (Figure 2) again suggest that, although there was no correlation between genotype and sport performance, it can be hypothesized that RX genotype would help to resist long and hard training and that is the reason that we found a higher prevalence of RX genotype among the older AS swimmers.

The correlations between the different tests performed by the girls and the scores in the Figure competitions indicate that the tests are good predictors of AS performance. The weakest correlation was found in the case of the only out-of-water test, the ball launch, also the less specific AS test, although it is performed by the swimmers in some evaluation tests of the Spanish Swimming Federation. Peric *et al.* (12) found a similar correlation of boost, although the measurement system was different, and another specific AS element with the scores in the Solo routine of 16 to 18 year-old artistic swimmers and our results extents the correlation to less specific abilities and in more age groups. Remarkably, we found few correlations between the physical tests and anthropometric data. The less specific test, the ball launch, correlated positively with BMI and body fat in the 13-15 group and the whole group of swimmers, indicating high BMI and body fat content in these ages favours out-of-water strength. The boost test (normalized) correlated negatively with BMI in the older group, similarly to Peric *et al*. (12), but the correlation was positive (but weak) when the whole group was considered (Figure 4). This result can be explained as, for the youngest girls, a higher BMI can indicate more strength to perform the boost, but in the case of 16-17 year-old girls, who had higher BMI and boost measures, a “lighter” BMI can be an advantage.

No correlation was found between the anthropometric measures and the scores in competition in the girls analysed in this study (9-17 years old). A similar result was also obtained by Salber *et al*. (15) with respect to artistic swimmers 15-17 years old in performance in Figure competition, indicating that the practice of selecting athletes of given physical traits (3) has a questionable predictive value. The result is important because to take into account such result could prevent relinquishments, RED-S and eating disorders (23).

Conclusions

Artistic swimming in the age groups ≤ 12, 13-15 and 16-17 years old could have an impact on body mass index, triceps skinfold, weight and menarche age of practising girls. With respect to genotype *ACTN3* R577X, a higher prevalence of heterozygous genotype RX was observed in the older group. This genotype could give an advantage in a power sport with long training as artistic swimming. On the other hand, the specific performance of the artistic swimmers showed little linking to anthropometric measures.

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