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Anthropometry

Leg length (measured at the gluteal furrow) and arm span (measured from the tip of the middle finger of one hand to the other) were obtained with a polyester measuring tape and an anthropometer. After height and body-mass measurements, the percentage of fat body mass (%FBM) was estimated from the skinfold thickness, expressed in millimeters, of the sum of 4 skin areas (biceps, triceps, subscapula, and suprailiac) measured on the right side of the body with Harpenden skinfold calipers, following the method described by Durnin and Rahaman.¹⁶ Sexual maturation was evaluated from the puberty stages of Tanner¹⁷ by the physician in charge of the swimming league.

Buoyancy was evaluated by measuring hydrostatic lift (HL) as described by Chatard et al.¹⁸ This was measured at the end of a maximal inspiration when the subjects were floating in the fetal position facing downward. Lead weights, varying from 0.1 kg to 1 kg, were successively applied to the back at the level of the shoulder blades. The final load necessary to maintain the subjects in a balanced position just under water was considered HL. This method has been shown to be highly reliable ($r = .98$ for 8 swimmers)¹⁶ and is easy to use.

Jump-and-Reach Test

The jump-and-reach test was performed using an Ergojump (Jump-MD, Takei, Japan). The subjects were asked to perform a countermovement jump (CMJ) as previously described.¹ The power output during the jump-and-reach test was determined by entering the jump-height and body-weight variables into the equation of Sayers et al,¹⁹

$$\text{CMJ}_{\text{peakP}} (\text{W}) = 51.9 \times \text{CMJ height (cm)} + \text{body mass (kg)} - 2007$$

where $\text{CMJ}_{\text{peakP}}$ is the peak power obtained with the CMJ and CMJ height is the height attained.

A standardized 15-minute warm-up was performed by all subjects 10 minutes before the test. This warm-up was exclusively composed of lower limb stretching movements (knee flexors and extensors).

Performance

The day of the anthropometric measurements, the swimmers performed two 15-m sprints without diving, and the best performance was kept as their maximal swim speed. The best performance in a 400-m competitive event in a 50-m swimming pool at the time of the current season (ie, within the last 2 months) was recorded for each swimmer.

Glide

The passive-glide measure (ie, without any kicking phase) was the distance attained by the swimmer's head after a push on the swimming pool wall in the prone ventral hydrodynamic position at a depth between 0.5 m and 1 m.²⁰ Each swimmer performed the test 3 times to become

familiar with it and to find the best gliding position. The best distance was retained.

Estimated Maximal Aerobic Power

The outdoor incremental test was the University of Montréal track test,²¹ an indirect continuous multistage test that is valid and reliable for estimating indirect maximal aerobic power ($e\text{VO}_{2\text{max}}$) from maximal aerobic velocity. The subjects ran along markers placed every 20 m on a 400-m track and were paced by audible cues. The interval between cues decreased gradually (every 1 min), and the subjects thus had to increase their speed ($0.5 \text{ km} \cdot \text{h}^{-1} \cdot \text{min}^{-1}$) to keep pace with the cues.

Statistical Analysis

All values are expressed as mean \pm SD. A 2-way (sex \times age) ANOVA for unpaired populations was applied, with post hoc analysis if necessary. When statistical significance was observed, post hoc analysis was done. Pearson product-moment correlations describe the relationship between the individual anthropometric and physiological variables and 400-m performance.

Sex-specific and nonspecific multiple linear models were developed to identify the best combinations of multiple simultaneous determinants of the 400-m and 15-m sprint performances from the initial set of variables. A multipronged strategy was adopted for data selection after checking for assumptions. This consisted of examining the possible regression methods (backward, forward) to check for the consistency of the significant variables and for model optimization. The probabilities of F-to-enter and F-to-remove were .05 and .10, respectively. The adjusted r^2 values are provided in the results. The equations resulting from the regression analysis were applied to estimate 400-m performance and to relate it to the actual measured performance.

The boys in the 2011 elite subgroup were compared with the other boys age 10 to 12 years in 2004, through unpaired Student t tests performed on all anthropometric, physiological, and performance variables. Binary logistic-regression analysis was performed to determine the significant predictors of endpoint level of practice in 2011 (elite or not) from the following initially measured variables: height, leg length, arm span, weight, %FBM, $e\text{VO}_{2\text{max}}$, $\text{CMJ}_{\text{peakP}}$, power output, glide, HL, and 400-m-crawl performance. Because of missing data points, the analysis included 5 elite and 28 nonelite swimmers.

We used the Statistical Package for Social Sciences (SPSS), version 18.0. For all statistics, a significance level of $P < .05$ was preset.

Results

Anthropometry

As presented in Table 1, all the anthropometric data except %FBM changed with age. There were no differences in anthropometric data between boys and girls

Parameters Involved in 400-m Performance

The 400-m distance is a valid test to evaluate maximal aerobic power in swimmers³⁸ and is regularly used in the literature. The performance during the 400-m swim could be favorably compared with the times noted in the literature for the same age and the same sex (399–335 s for 400-m in boys 11–14 y and 374–367 s for 400-m in girls 12.5–13.5 y).^{23,24,26,27,39} In contrast, the results of the 2011 elite subgroup were better than those noted in the literature (ie, a mean of 330 s for the 400-m in 10- to 12-y-old boys).

Performance was poorly but significantly correlated with glide, age, and eVO_{2max} , indicating that the older children with better glide and better eVO_{2max} demonstrated better performance in the 400-m swimming trial. These results agree with the literature, which shows a correlation with direct or indirect VO_{2max} in young swimmers.^{23,24,26,39} We measured indirect VO_{2max} with a running test known to show higher results with longer leg length and greater running economy, and these 2 factors are well known to improve with age. It was therefore not surprising that 400-m performance was also related to age, as older swimmers normally swim with better efficiency than do younger ones.²⁵ Lätt et al²⁶ demonstrated that 400-m performance increases with age according to increases in body height and arm span and improvement in VO_2 , as well as in relation to technical factors.

The implication of the glide in 400-m performance emphasizes the importance of underwater resistance in swimming. Glide's effect on swimming performance has been studied during short swimming durations and consecutive to the start and grab phases^{40,41} or across passive drag.¹⁸ The following has been demonstrated: Swimmers with longer glides usually have the most effective hydrodynamic position to avoid a high loss of velocity during the glide,^{40,41} and a good glide associated with low passive drag should be considered a good indicator of general aptitude for swimming.¹⁸ It is not certain, however, that the swimmers with better passive drag (ie, better glides) are more economical during active drag, because 400-m swimming performance in a 25-m pool means 15 glides, which could amount to substantial energy conservation for swimmers with a better glide. Sanders and Byatt-Smith⁴² demonstrated that starting aquatic propulsion too early (ie, opposite the glide) raises the energy cost of swimming, and Vantorre et al^{40,41} suggested that a longer gliding phase (ie, after the start phase and after each "flip turn") is more economical because the swimmers do not act to move forward and remain in a hydrodynamic position. Moreover, Chatard et al¹⁸ showed a correlation with passive drag and swimming performance.

When boys and girls were separated, the factors implicated in the variability of 400-m performance were age and eVO_{2max} in boys ($r^2 = 0.431$, $P < .01$) and leg length, eVO_{2max} , and glide in girls ($r^2 = .229$, $P < .01$). The finding that age was not correlated in girls and was replaced by an anthropometric parameter (ie, leg length) may be explained by different maturation rates in boys

and girls of the same age, with girls attaining final maturation (ie, reflected by the Tanner stage) earlier.

Girls Versus Boys

We did not see a sex \times age effect, but some parameters demonstrated a sex effect: The girls were significantly fatter, had lower eVO_{2max} and CMJ_{peakP} , and demonstrated lower performance for both the 400-m and 15-m trials. The results on body fat and VO_{2max} were reported for older boys and girls involved in swimming activity (ie, 13–15 y old),³⁸ as well as for school children.³² This sexual dimorphism is notable in puberty, which is associated for girls with significantly lower hemoglobin values and higher fat mass due to hormonal effects.⁴³

Although we found no significant sex \times age difference in 400-m performance, the girls increased their 400-m speed up to 13 years old and then stagnated, whereas the 400-m speed in boys continued to rise. Our results agree with findings that the most consistent rapid rise in swimming speed occurs from 11 to 13 years in boys⁴⁴ and girls.³⁹ However, although a slow increase in swimming speed is noted at 13 to 14 years followed by a second acceleration from 14 to 16 years of age,⁴⁴ which we noted in our girls, our boys demonstrated a stagnation at 12 and 13 and an acceleration at 14, certainly in relation to greater maturation and thus more muscle power at 14 than at 12 and 13 years old. This interpretation is consistent with the increase in Tanner stage in our boys at 14 years compared with 12 and 13. The significantly better 15-m performance in boys was consistent with greater muscle development, as reflected by the greater CMJ_{peakP} .

The 2011 Elite Subgroup

Costa et al⁴⁵ demonstrated that performance is not stable in young white swimmers until about 16 years of age, and therefore predictions of future performance are not really robust until data at 16 years are available. Nevertheless, it was very interesting to note that 3 of the 4 variables predictive of skill level were significantly better in the 2011 elite subgroup 7 years later (ie, CMJ_{peakP} , glide, and 400-m performance), which suggests that future elite swimmers are discriminated by CMJ_{peakP} , glide, HL, and 400-m performance and had better CMJ_{peakP} , glide, and 400-m. As CMJ_{peakP} was better in the 2011 elite group and may be linked to the glide (ie, swimmers with better leg power push harder on the wall, thereby having the best glide result), we investigated the glide: CMJ_{peakP} ratio. We found that the ratio did not differ between the 2011 elite subgroup and their counterparts (ie, 2.44 ± 1.28 vs 2.87 ± 1.27 in elite vs their counterparts for the [glide/ $CMJ_{peakP} \times 1000$] ratio; arbitrary units). This indicates that the better glide noted in the 2011 elite subgroup was not due to the better CMJ_{peakP} but certainly to more effective hydrodynamic characteristics.

However, the better CMJ_{peakP} denoted higher explosivity in the 2011 elite subgroup, which was confirmed by the better 15-m performance. This latter was

not a discriminating factor between the elite and nonelite swimmers in our study, and it is not a key factor of 400-m performance, as long-distance characteristics differ from those of sprint events.⁴⁶

Perspective

This study demonstrated that (1) although the Guadeloupean swimmers were fatter than most white swimmers of the same age, they had very poor HL, certainly in relation with ethnic characteristics; (2) they had better CMJ_{peakP}, also certainly in relation with ethnic characteristics; and (3) they performed as well as their white counterparts at the same age. The top 2 swimmers of Afro-Caribbean origin selected for the French team for both international and Olympic competition (ie, Julien Sicot and Malia Metella) were both sprinters, but only 1 of the 6 young swimmers of the current study is now a sprinter. This means that our young swimmers with great explosivity and poor HL, who were discriminated by important parameters implicated in long-distance swimming (400-m performance, a reflection of aerobic power) and glide, did not succeed in sprint events at an international level but in longer ones.

Further research is needed to investigate the motor organization and energy cost of swimming in Afro-Caribbean swimmers, because they clearly are different from those noted in whites.

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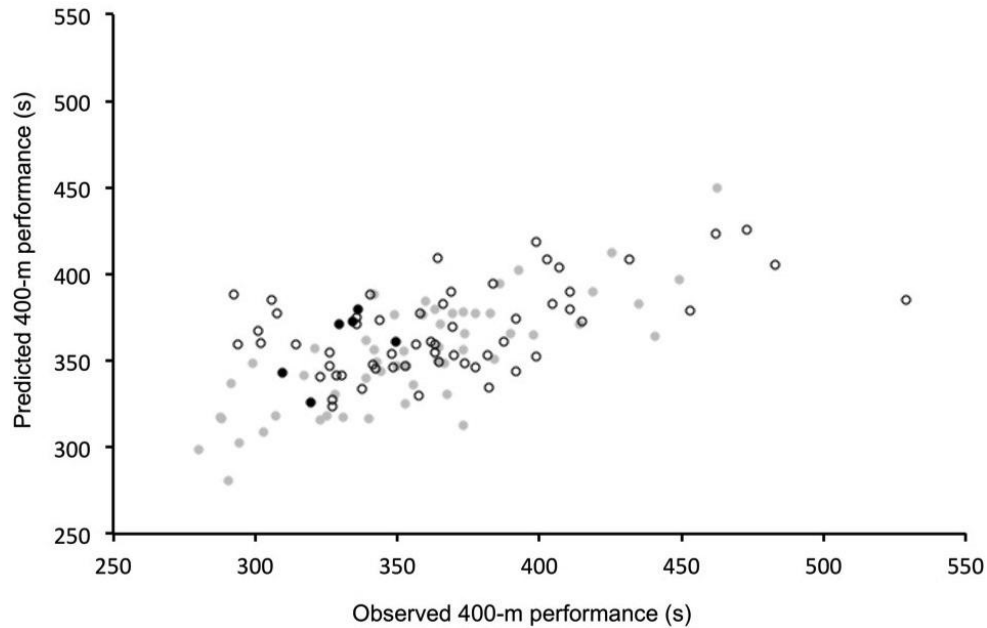


Figure 1 — Observed and predicted sex-specific 400-m performance in future high-level performers (black circles) and in other boys (gray circles) and girls (white circles).

Table 1 Anthropometric Differences Between Boys and Girls Over Time

	Age, y	n	Tanner stage	Height, cm*	Leg length, cm*	Arm span, cm*	Weight, kg*	Body fat, %
Boys	10	9	1–2	148.1 ± 12.6	70.5 ± 5.3	156.0 ± 13.8	39.9 ± 11.2	17.5 ± 5.0
	11	14	1–2	152.3 ± 5.9	71.1 ± 5.5	156.1 ± 9.5	41.3 ± 8.1	20.6 ± 4.4
	12	16	1–2	155.9 ± 6.2 ^{a,b}	76.9 ± 4.3 ^{a,b}	165.1 ± 11.2 ^b	45.1 ± 8.9	15.6 ± 3.5
	13	12	1–3	169.7 ± 5.5 ^{a,b,c}	79.7 ± 4.9 ^{a,b}	177.3 ± 7.4 ^{a,b,c}	51.3 ± 7.5	16.6 ± 5.3
	14	10	2–4	170.4 ± 9.3 ^{a,b,c}	82.2 ± 5.4 ^{a,b,c}	175.7 ± 13.3 ^{a,b,c}	59.5 ± 12.4	19.9 ± 8.0
mean				159.0 ± 11.6	76.1 ± 6.6	166.1 ± 13.7	46.8 ± 11.3	17.9 ± 5.5
Girls	10	12	1–2	144.8 ± 7.1	68.7 ± 4.9	152.2 ± 10.1	39.3 ± 6.7	29.6 ± 4.7
	11	17	1–3	154.9 ± 7.4 ^a	74.7 ± 7.3 ^a	160.1 ± 9.8	43.2 ± 7.4	24.9 ± 4.4
	12	19	2–4	158.4 ± 4.6 ^a	75.2 ± 4.3 ^a	166.7 ± 7.6 ^a	46.6 ± 8.0 ^a	25.3 ± 6.1
	13	8	3–5	163.1 ± 5.4 ^{a,b}	81.1 ± 5.1 ^{a,b,c}	171.4 ± 10.1 ^a	54.1 ± 4.8	28.9 ± 4.8
	14	9	3–5	163.7 ± 6.3 ^{a,b,c}	77.8 ± 5.3 ^a	170.3 ± 8.3 ^{a,b}	55.9 ± 10.2	27.7 ± 3.2
mean				156.8 ± 8.4	75.3 ± 6.4	165.0 ± 10.4	47.0 ± 9.3	26.6 ± 5.2

Note: Bold indicates sex effect: different from boys at the same age ($P < .001$).

*Age effect ($P < .001$): a, different from 10 y; b, different from 11 y; c, different from 12 y ($P < .05$).

Table 2 Physiological and Performance Results

	Age, y	n	eVO _{2max} , mL · min ⁻¹ · kg ⁻¹ *	MAV, km · h ⁻¹	CMJ, cm*	CMJ _{peakP} , W*	HL, kg	Glide, m*	400-m, s	15-m, s
Boys	10	9	51.3 ± 3.9	9.4 ± 2.1	43.2 ± 9.3	2079 ± 549	1.1 ± 0.6	7.7 ± 1.0	389 ± 47	10.7 ± 0.7
	11	14	50.6 ± 3.0	9.7 ± 1.6	45.4 ± 6.6	2367 ± 559	1.2 ± 0.8	6.9 ± 1.1	371 ± 30	10.3 ± 0.6
	12	16	52.3 ± 5.1	11.3 ± 2.3	47.7 ± 5.2	2672 ± 511 ^a	1.1 ± 0.5	7.7 ± 1.3	348 ± 39 ^a	10.0 ± 0.9
	13	12	54.8 ± 4.6 ^b	12.9 ± 2.4 ^{a,b}	48.0 ± 7.9	2995 ± 504 ^{a,b}	1.0 ± 0.7	7.2 ± 1.0	347 ± 34 ^a	10.0 ± 0.7
	14	10	57.0 ± 4.6 ^{a,b,c}	13.8 ± 3.0 ^{a,b,c}	50.8 ± 7.2	3588 ± 699 ^{a,b,c}	0.8 ± 0.5	8.6 ± 1.1 ^{b,d}	310 ± 33 ^{a,b,c,d}	9.7 ± 0.6
mean			45.4 ± 4.5	5.7 ± 1.7	39.1 ± 5.1	1948 ± 457	1.2 ± 0.9	7.5 ± 1.3	397 ± 74	11.8 ± 1.2
Girls	10	12	47.8 ± 4.1	8.6 ± 2.2	41.0 ± 4.1	2243 ± 275	1.0 ± 0.6	7.2 ± 1.3	381 ± 39	10.6 ± 0.8
	11	17	49.1 ± 2.4^a	8.8 ± 1.5^a	42.2 ± 4.7	2393 ± 400 ^a	1.3 ± 0.7	8.6 ± 1.4 ^b	352 ± 41	10.6 ± 1.2
	12	19	48.8 ± 2.4	8.3 ± 1.8^a	48.1 ± 5.4	3019 ± 282 ^{a,b,c}	1.3 ± 0.4	7.2 ± 2.3	348 ± 31	10.9 ± 0.3
	13	8	48.7 ± 3.8	10.5 ± 1.8^a	42.2 ± 7.0	2690 ± 226^{a,b,d}	1.5 ± 0.8	9.8 ± 0.3 ^{a,b}	356 ± 23	10.4 ± 0.6
	14	9								
mean			48.1 ± 3.6	8.5 ± 2.1	42.2 ± 5.6	2397 ± 466	1.3 ± 0.7	8.0 ± 1.5	367 ± 48	10.9 ± 1.0

Abbreviations: eVO_{2max} indicates estimated aerobic power; MAV, maximal aerobic velocity; CMJ, countermovement jump; CMJ_{peakP}, CMJ peak power; HL, hydrostatic lift. Note: Bold indicates sex effect: different from boys at the same age ($P < .001$).

*Age effect ($P < .001$). a, different from 10 y; b, different from 11 y; c, different from 12 y; d, different from 13 y ($P < .05$).

Table 3 Anthropometric Differences Between Elite and Nonelite Swimmers

	n	Age, y	Height, cm	Leg length, cm	Arm span, cm	Weight, kg	Body-fat mass, %
Elite	6	11.5 ± 0.8	158.1 ± 12.4	74.2 ± 6.2	168.6 ± 14.8	46.9 ± 10.6	18.7 ± 1.2
Nonelite	33	11.1 ± 0.3	151.8 ± 9.6	73.2 ± 5.7	158.1 ± 10.6*	41.6 ± 9.0	17.6 ± 5.1

* $P < .05$.

Table 4 Physiological and Performance Results in Elite Versus Nonelite Swimmers

	n	eVO _{2max} , mL · min ⁻¹ · kg ⁻¹	CMJ _{peakP} , W	HL, kg	Glide, m	400-m, s	15-m, s
Elite	6	51.9 ± 4.3	2793 ± 597	1.1 ± 0.4	9.3 ± 0.6	330 ± 16	9.3 ± 0.6
Nonelite	33	45.0 ± 6.5	2357 ± 556*	1.1 ± 0.6	7.2 ± 1.1*	374 ± 40*	10.5 ± 0.7*

Abbreviations: eVO_{2max} indicates estimated aerobic power; CMJ_{peakP}, countermovement peak power; HL, hydrostatic lift.

* $P < .05$.