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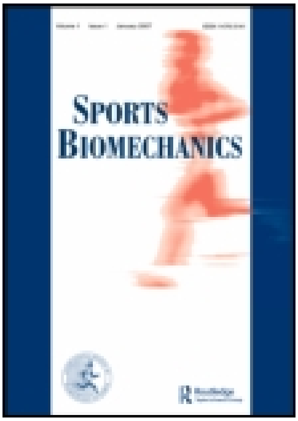

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Swimming

Huub M. Toussaint [a], Martin Truijens [a], Meint-Jan Elzinga [a], Ad Van de Ven [a], Henk de best [a], Bart Snabel [a] & Gert de Groot [a]

[a] Institute for Fundamental and Clinical Human Movement Science Faculty of Human Movement Science, Vrije Universiteit, The Netherlands

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Effect of a Fast-skin™ 'Body' Suit on Drag during Front Crawl Swimming

HUUB M. TOUSSAINT, MARTIN TRUIJENS,
MEINT-JAN ELZINGA, AD VAN DE VEN, HENK DE BEST,
BART SNABEL, and GERT DE GROOT

ABSTRACT

The effect on drag of a Speedo Fast-skin suit compared to a conventional suit was studied in 13 subjects (6 males, 7 females) swimming at different velocities between 1.0 and 2.0 m•s^{-1}. The active drag force was directly measured during front crawl swimming using a system of underwater push-off pads instrumented with a force transducer (MAD system). For a range of swimming speeds (1.1, 1.3, 1.5 and 1.7 m•s^{-1}), drag values were estimated. On a group level, a statistically non-significant drag reduction effect of 2% was observed for the Fast-skin suit (p = 0.31). Therefore, the 7.5% reduction in drag claimed by the swimwear manufacturer was not corroborated.

INTRODUCTION

In competitive swimming the resistance (drag) encountered is considered to be a major performance factor (Maglischo, 1993). This drag consists of skin friction (F_f), pressure drag (F_p) and wave-making resistance (F_w) since the largest part of competitive races occurs at the water-air interface. Hence, total drag (F_d) equals:

$$F_d = F_f + F_p + F_w \quad \text{(Toussaint } et\ al., \text{ 2000)} \qquad (1)$$

Given that success or failure in competition often is measured in hundredths of seconds, it is valuable to study the possible effect of swimwear on total drag. In 1989, drag reduction effects of wearing a triathlon suit were reported by Toussaint *et al.* (1989). Following on from this, swimwear manufacturers have developed fabrics which supposedly reduce the friction of water flowing over the swimsuit. Previously, it was assumed that friction drag was negligible (< 5% of total drag) given the high Reynolds numbers (> 10^5) that occur during swimming (Toussaint *et al.*, 1988b). However, recently it was suggested that significant reductions in total drag could be accomplished by reducing pressure drag by the use of vortex generators minimizing separated flow (Waring, 1999).

Institute for Fundamental and Clinical Human Movement Science
Faculty of Human Movement Science, Vrije Universiteit, The Netherlands

In 2000, Speedo® introduced a new line of swimwear called Fast-skin™ in which the vortex generators were applied. According to Speedo: '*a swimmer can retain a better position in water which reduces form and friction drag. Combined with fabric that reduces friction drag, FASTSKIN contributes to the overall reduction of total drag*'. Based on *passive* drag tests, a reduction in total drag up to 7.5% is claimed when wearing the Fast-skin™ (Speedo press release: 'Fast-skin the facts'). However, the effects of the suit during *active* swimming remain to be determined. Further background information regarding the difference between active and passive drag can be found elsewhere (Toussaint *et al.*, 2000; Vaart *et al.*, 1987). Therefore, in the present investigation, the total active drag when swimming in the body Fast-skin was compared with that evoked when wearing conventional swimwear.

METHODS

To evaluate the influence of the Fast-skin suit, total drag for 13 subjects (7 females, 6 males, see Table 1) was measured while wearing the Fast-skin suit and again wearing conventional swimwear. The possible gender effect was analysed to investigate the possible flotation enhancement of the Fast-skin (body) suit. If true, a larger drag advantage is to be expected for the males who, on average, have a higher specific gravity.

Table 1 Individual Data for Gender, Age, Mass and Height

Subject	*Gender*	*Age* *yrs*	*Mass* *kg*	*Height* *m*
Annabel	F	23	75	1.80
Brenda	F	25	76	1.89
Chantal	F	18	65	1.73
Haaike	F	17	57.5	1.70
Joyce	F	16	72	1.78
Manon	F	18	66	1.70
Mellanie	F	?	67	1.83
Dennis	M	27	85	1.85
Ewoud	M	22	85	2.00
Fabian	M	?	83	1.91
Johan	M	20	78	1.87
Mark	M	26	79.5	1.86
Werner	M	22	85	1.93

The measurements were made using the system to Measure Active Drag (MAD-system (Toussaint *et al.*, 1988a)). Briefly, the system enables the swimmer to push off from fixed pads at each stroke. These push-off pads are attached to a 23 m-long rod. The distance between the push-off pads was 1.3 m, while the rod was mounted 0.8 m below the water surface. The rod was instrumented with a force transducer in order to measure the push-off forces. The force signal was low pass filtered (14 Hz cut-off frequency), digitized (1000 Hz sampling frequency), processed and stored on disk using an Apple Powerbook. The force signal pushing off from the second to the last (16th) pad is time-integrated and yields the average force swimming 14 x 1.35 = 18.9 m. The mean velocity was computed from the time taken to cover the distance between the second and last pad. The subjects used their arms only and the feet were supported by the same small pull buoy in the two conditions. At constant swimming velocity, the mean propelling force is equal to the mean drag force (Vaart *et al.*, 1987).

To measure drag and to establish the relationship between drag and swimming velocity, subjects were asked to swim 10 lengths, each at a different but constant velocity (Range: 1.0–1.7 m•s^{-1} for the females and 1.0–2.0 m•s^{-1} for the males). For each length, mean drag force and mean swimming velocity were measured. These 10 velocity/drag data were least square fitted to the function:

$$F_d = A \bullet v^n \qquad (2)$$

Where F_d represents total active drag, v equals swimming velocity and A and n are parameters of the power function. This function was chosen because total drag is dominated by pressure drag at the prevailing high Reynold's numbers of 2.10^6–4.10^6 (Toussaint *et al.*, 1988b).

All subjects used the Speedo Fast-skin *bodysuit,* in which trunk and legs are covered. The arms remained bare. For each subject, A and n were obtained via a least squares fit with a Levenberg-Marquardt algorithm using Matlab (Mathworks, Natick, Mass.). This was carried out once with the Fast-skin and once swimming with conventional swimwear (Table 2). These fitted functions were used to estimate the drag at four different velocities 1.1, 1.3, 1.5 and 1.7 m•s^{-1}. The effect on drag was evaluated by comparing the estimated drag swimming with the Fast-skin with the value obtained while swimming with conventional swimwear. Individual differences (in %) with respect to the drag when wearing conventional swimwear are presented in Table 3 at the four velocities studied.

The estimated drag values swimming with Fast-skin and with conventional swimwear at the four velocities were tested for differences using an Analysis of Variance with repeated measures using gender as a grouping variable and type of suit as a within-subject variable (STATISTICA 4.1 for the Macintosh, StatSoft, Inc., Tulsa, OK).

RESULTS

For most subjects, no reduction in drag was observed when wearing the Fast-skin (see Figure 1). Also, when all collected data points for all subjects in each condition were taken together and again were fitted to the power function, no clear active drag reduction effect of the Fast-skin could be detected. Parameters of the fitted curves for all subjects are presented in Table 2. From the fitted curves, estimations were made for the drag at velocities of 1.1, 1.3, 1.5 and 1.7 m•s^{-1}. The results are presented in Table 3.

The Analysis of Variance with repeated measures with gender as a grouping variable for the estimated drag values at 1.1, 1.3, 1.5, and 1.7 m•s^{-1} did not reveal a significant main or interaction effect (see Table 4). Hence, no significant

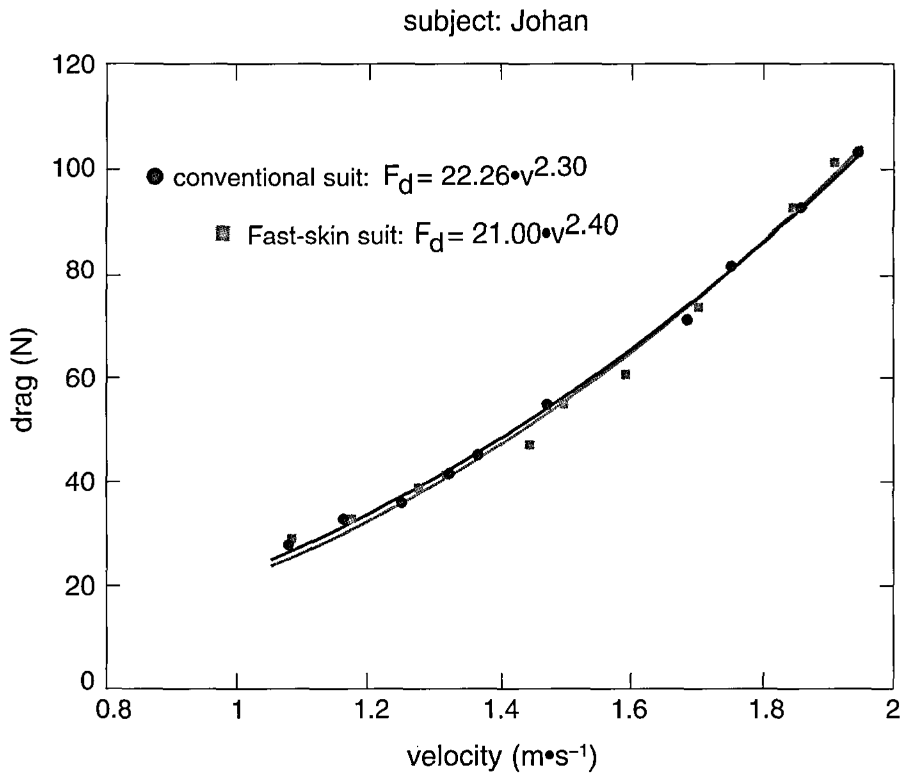

Figure 1 Drag data for one subject (Johan) showing active drag dependent on swimming velocity wearing the Fast-skin (grey squares) and conventional swimwear (black circles). Fitted curves are presented as well.

drag reduction effect of the Fast-skin could be detected. Consequently, it was not possible to detect gender-specific effects related to enhanced flotation.

For some subjects an active drag advantage seemed present. The most extreme case (Annabel) is shown in Figure 3. At 1.65 m•s^{-1} an 11% reduction in active drag was observed. However, even at that speed no statistically significant difference in drag was established between the conventional suit and the Fast-skin. From the residual sum of squares, the standard error for prediction was determined (Armitage, 1977). As indicated in Figure 3, the 95% confidence intervals of the two curves overlap at 1.65 m•s^{-1}. Therefore, no statistically significant drag reduction effect could be detected for this individual. It should be noted in the case of Annabel that the seemingly lower drag wearing the Fast-skin suit can also be caused by a less than perfectly fitted conventional suit. To illustrate this point two pictures of Annabel wearing the two suits are presented in Figure 4.

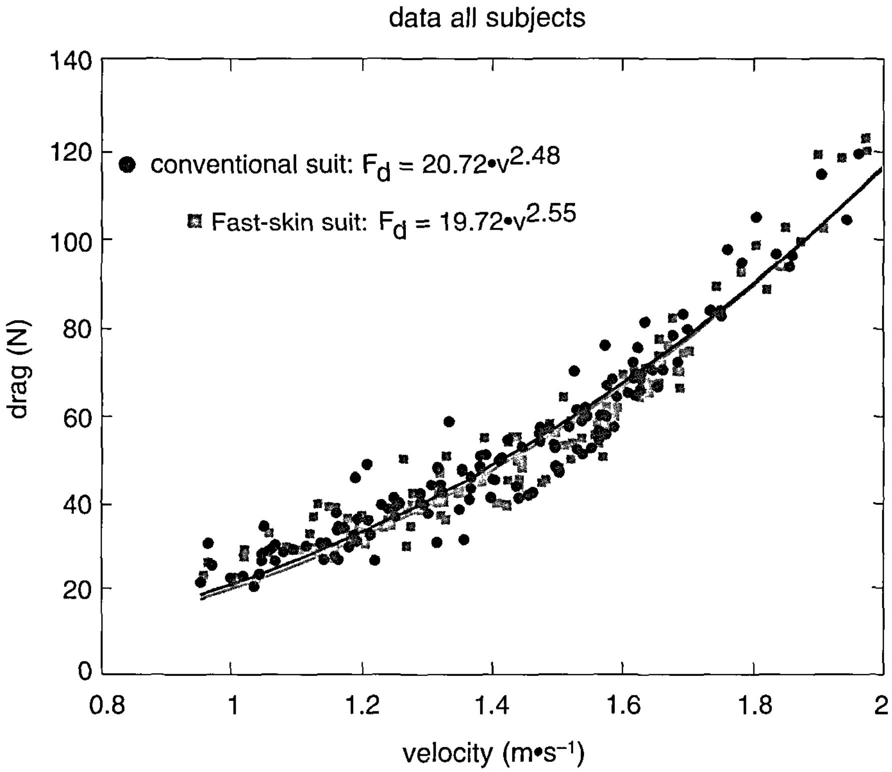

Figure 2 Drag data for all subjects showing active drag dependent on swimming velocity wearing the Fast-skin (grey squares) and conventional swimwear (black circles). Fitted curves are presented as well.

Table 2 Least Square Fitted Parameters Describing the Curves of the Drag Dependent on Velocity (Fd = A $\cdot$ v^n). A = a Coefficient of Proportionality, n = Power of the Velocity, Fd = Drag (N)

	Conventional Suit		*Fast-skin*	
	A	*n*	*A*	*n*
Females				
Annabel	23.32	2.29	21.66	2.23
Brenda	19.78	2.47	21.25	2.27
Chantal	14.32	2.87	19.27	2.25
Haaike	18.37	2.44	16.43	2.65
Joyce	22.09	1.91	21.85	1.93
Manon	22.16	2.21	20.73	2.34
Mellanie	23.22	2.15	21.84	2.17
Males				
Dennis	21.80	2.49	23.89	2.36
Ewoud	23.71	2.35	23.35	2.37
Fabian	22.36	2.34	23.04	2.17
Johan	22.26	2.30	21.00	2.40
Mark	23.08	2.28	23.17	2.27
Werner	31.55	1.96	27.48	2.19

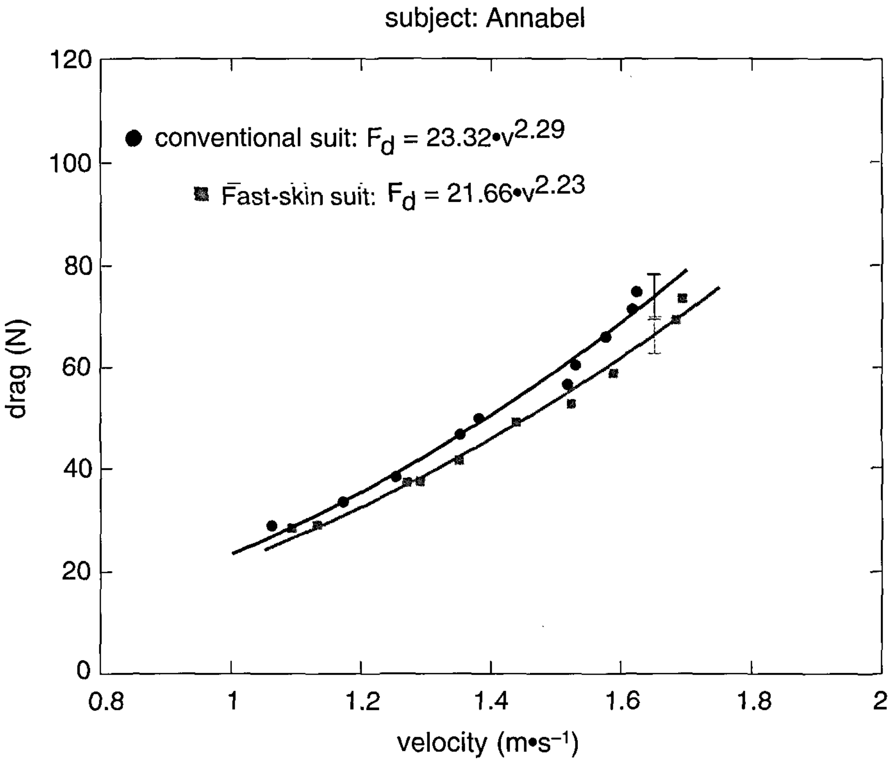

Figure 3 Drag data for one subject (Annabel) showing active drag dependent on swimming velocity wearing the Fast-skin (grey squares) and conventional swimwear (black circles). At 1.65 $m \cdot s^{-1}$ overlapping confidence intervals of the drag-velocity-curves are plotted, indicating non-significant differences in drag.

DISCUSSION

In competitive swimming events, the difference between success and failure may be 0.01 s. Therefore, small reductions in active drag would be important for the swimmer. Since active drag is dominated by pressure drag, drag reduction would be most effectively accomplished by the legs floating higher. The higher leg position will enhance a streamlined position and reduce the frontal area. This seems indeed the major effect of wearing a triathlon wetsuit that causes significant active drag reductions (Toussaint *et al.*, 1989). However, according to FINA rules, flotation enhancement is not allowed. In that context swimwear manufacturers try to optimise their products by focusing on the reduction of skin friction and by postponing flow separation that will reduce pressure drag (Waring, 1999).

Table 3 An Estimation of the Drag (F_d) in Newtons at Velocities of 1.1, 1.3, 1.5 and 1.7 m • s⁻¹ is Given Swimming with Conventional Swimwear (conv) and with Fast-skin (Fast). Difference Expressed in % in Drag Wearing the Fast-skin is Given Relative to the Drag Value while Swimming with Conventional Swimwear.

	Drag 1.1 m•s⁻¹			*Drag 1.3 m•s⁻¹*			*Drag 1.5 m•s⁻¹*			*Drag 1.7 m•s⁻¹*		
	Conv	*Fast*	*−%*	*Conv*	*Fast*	*−%*	*Conv*	*Fast*	*−%*	*Conv*	*Fast*	
Females												
Annabel	29.01	26.78	−8.4	42.55	38.84	−9.6	59.08	53.4	−11	78.72	70.56	−11.6
Brenda	25.02	26.37	5.1	37.79	38.51	1.9	53.8	53.26	−1.0	73.27	70.72	−3.6
Chantal	18.83	23.88	21.2	30.41	34.79	12.6	45.85	48.01	4.5	65.67	63.64	−3.2
Haaike	23.18	21.16	−9.6	34.83	32.94	−5.7	49.36	48.15	−2.5	66.97	67.1	0.2
Joyce	26.51	26.25	−1.0	36.48	36.20	−0.8	47.68	47.68	−0.6	60.90	60.67	−0.4
Manon	27.35	25.9	−5.6	39.26	38.26	−3.3	54.21	53.45	−1.4	71.45	71.61	0.2
Mellanie	28.51	26.86	−5.8	40.85	38.59	−5.5	55.59	52.65	−5.3	72.79	69.08	−5.1
		mean	*−0.6*		***mean***	*−1.5*		***mean***	*−2.4*		***mean***	*−3.4*
Males												
Dennis	27.65	29.92	7.6	41.93	44.39	5.5	59.92	62.22	3.7	81.86	83.61	2.1
Ewoud	29.67	29.26	−1.4	43.97	43.46	−1.2	61.59	61	−1.0	82.69	82.05	−0.8
Fabian	27.96	28.32	1.3	41.37	40.68	−1.7	57.86	55.48	−4.3	77.59	72.77	−6.6
Johan	27.71	26.4	−4.9	40.68	39.44	−3.2	56.53	55.62	−1.6	75.37	75.12	−0.3
Mark	28.68	28.77	0.3	41.95	42.03	0.2	58.11	58.15	0.1	77.28	77.24	0.0
Werner	38.05	33.85	−12	52.83	48.8	−8.3	69.98	66.74	−4.9	89.49	87.77	−2.0
		mean	*−1.6*		***mean***	*−1.4*		***mean***	*−1.3*		***mean***	*−1.3*

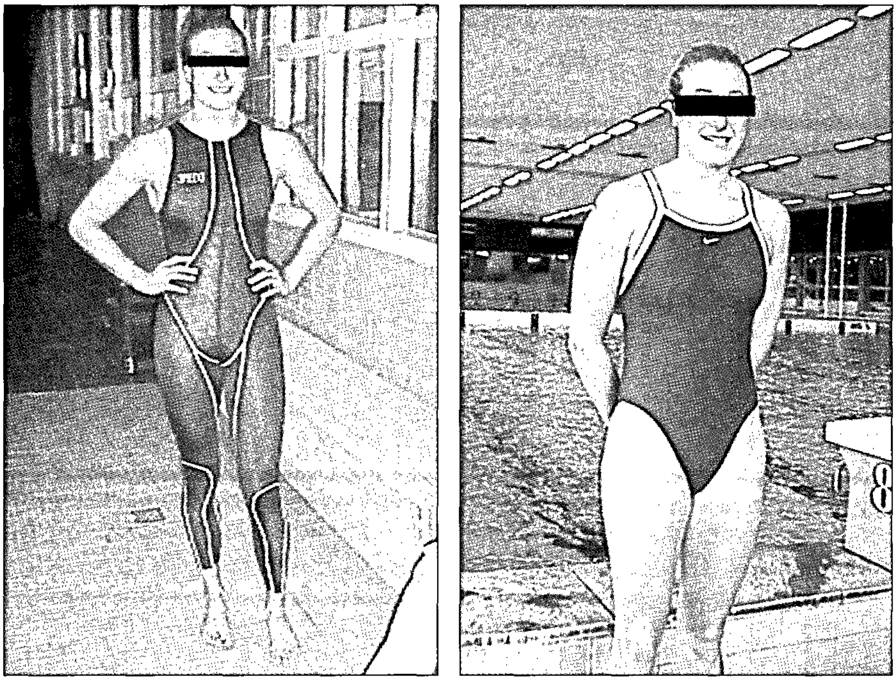

Figure 4 Subject Annabel wearing the Fast-skin (left) and conventional swimwear (right).

Table 4 ANOVA with Repeated Measurements with Gender as Grouping Variable and Suit Type as a Within Subject Variable

Effect	*Wilk's Lambda*	*Rao's R*	*df 1*	*df 2*	*p-level*
Gender	0.40	3.04	4	8	.08
Suit	0.62	1.26	4	8	.36
Gender x Suit	0.81	0.48	4	8	.75

Given the relatively small contribution of skin friction to total active drag, the possible effect on total drag of using friction-reducing fabrics can only be small. Postponing flow separation seems a promising approach. However, it requires an adequate size of vortex generators (protrusion into the boundary layer of about 4 mm!) as well as an adequate placement of them i.e. just upstream to where flow-separation is imminent (Waring, 1999). In the tested suits these requirements were apparently not met. However, the tight suit might prevent large oscillating deformations of subcutaneous adipose tissue when swimming at higher speeds (Aleyev, 1977). Furthermore, the rate of energy expenditure (power) during swimming relates to the drag coefficient times the cube of the swimming velocity (Toussaint *et al.*, 2000). For example, a 10% reduction of the drag coefficient translates into a 3.6% swimming velocity increase only. Nevertheless, if the claim that the Fast-skin suit reduces total drag by 7.5% is correct, a 2.5% increase in swimming velocity could be expected, with concomitant reductions in race times when wearing the suit. A 2.5% reduction in 100 m race time (2.5% of 49 s = 1.2 s) would provide a large competitive advantage.

The results of this study do not concur with the drag reduction claims proposed by Speedo (2000). No statistically significant effect could be detected for the whole group and this would be expected if a consistent drag reduction effect was present. For some subjects reduced drag was observed but the largest observed difference in drag between swimming with the Fast-skin and conventional suits was not significant.

Although no significant main effect of the suit on drag was found and although no significant gender effect could be demonstrated, it was found that the greatest average drag effect was recorded for the women at 3.4%. The males recorded their greatest drag reduction at 1.3%. This seems to indicate that if the Fast-skin would have an effect it would not be by enhanced flotation.

The application and possible limitations of the MAD system to the measurement of active drag in front crawl swimming are outlined in earlier papers (Toussaint *et al.*, 1988a; Toussaint *et al.*, 1988b; Vaart *et al.*, 1987). Currently, it is probably the best of several alternatives available for estimating drag force during front crawl swimming. Furthermore, it should be realised that the absence of drag reduction found in the present study when wearing the Fast-skin suit compared with conventional suits, are determined under otherwise identical conditions during swimming on the MAD system.

In conclusion, the present observations do not corroborate the 7.5% drag reduction claimed by Speedo as the benefit from wearing the Fast-skin. No statistically significant reduction in drag was found.

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