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ORIGINAL ARTICLE

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The effects of drafting on stroking variations during swimming in elite male triathletes

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Abstract The aim of this study was to determine the effects of drafting behind another swimmer on the metabolic response and stroke characteristics. Six highly trained male triathletes performed two maximal 400-m swims, one in a drafting (D) and one in a non-drafting condition (ND). Their metabolic response was assessed by measuring the oxygen uptake ($\dot{V}O_2$) and the blood lactate concentration at the end of each 400 m. Swimming velocity, stroke frequency, stroke length, and stroke index (velocity multiplied by stroke length) were recorded every 50 m. In the D and ND conditions, there was no difference in $\dot{V}O_2$ [66.7 (1.7) ml · kg^{-1} · min^{-1} vs 65.6 (1.2) ml · kg^{-1} · min^{-1}, respectively], however, the lactate concentrations were lower in D than in ND [9.6 (0.9) mM vs 10.8 (0.9) mM, respectively, $P < 0.01$]. In D, the performance [1.39 (0.02) m · s^{-1} vs 1.34 (0.02) m · s^{-1}, respectively, $P < 0.01$] and the stroking parameters (i.e., stroke length and stroke index) increased significantly, while the stroke frequency remain unchanged. In D, a stable pace was maintained, while in ND, velocity decreased significantly throughout the 400 m. In D, the performance gains were related to the 400-m D velocity ($r = 0.78$, $P < 0.05$), and to the body fat mass (BFM, $r = 0.99$, $P < 0.01$). The stroke index in D was also related to BFM ($r = 0.78$, $P < 0.05$). Faster and leaner swimmers achieved greater performance gains and stroke index when drafting. Thus, drafting during swimming increases the performance and contributes to the maintenance of stable stroking parameters such as stroke frequency and stroke length during a 400-m swim.

Key words Blood lactate · Exercise · Oxygen consumption · Performance · Swimming technique

Introduction

In 1995, the International Triathlon Union changed the rules to allow drafting during cycling (i.e. cycling directly behind another cyclist). In the swimming part of the triathlon, drafting has also become more important. Indeed, triathletes attempt to swim as fast as possible to stay in the leading group. In drafting swimming, it has been demonstrated that the metabolic demand is modified (Basset et al. 1991), as in cycling (McCole et al. 1990; Olds et al. 1995), cross-country skiing (Bilodeau et al. 1994, 1995), kayaking (Gray et al. 1995) or speedskating (Rundell 1996). In addition, it has been shown to improve the subsequent running performance when used during the cycling part of a triathlon (Hausswirth et al. 1999).

Chatard et al. (1998) showed that swimming behind a leader results in an increase in swimming velocity (by 3.2%) and stroke length, and a reduction in blood lactate concentration and stroke frequency. These authors found that the performance gain was related to the ability of the swimmer and his/her skinfold thickness, with faster and leaner swimmers achieving a greater performance gain.

In swimming, performance and energy cost are related to stroke frequency and stroke length (Costill et al. 1985; Craig et al. 1985; Chatard et al.1990a; Wakayoshi et al. 1995). Chollet et al. (1997) demonstrated that elite swimmers maintain a constant pace with constant

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velocity, stroke frequency and stroke length throughout a 100-m freestyle performed in real competition. Similar findings have been found for running, where small changes in velocity, stride frequency, and stride length, have been related to higher efficiency, lower energy cost and better performance (Cavanagh and Williams 1982; Martin and Morgan 1992).

Thus, triathletes need to be as efficient as possible in swimming to save energy for the cycling and running stages. However, the stroking characteristics used during drafting versus non-drafting swimming have never been investigated. The present study was undertaken primarily to investigate the metabolic response and the stroking characteristics used during drafting swimming.

Methods

Subjects

Six internationally ranked male triathletes participated in this study. All of the subjects agreed to participate voluntarily and gave their written informed consent. Approval for the project was obtained from the University Committee on Human Research. The measurements were made over a 3-day period, at the same time each day, for each experiment in drafting (D) and non-drafting (ND) situations.

Anthropometric measurements

After measurement of the subjects' height and body mass, body fat content was estimated from the skinfold thickness, expressed in mm, and representing the sum of four different sites (biceps, triceps, subscapula and supra-iliac) measured on the right side of the body with Holtain calipers, following the method described by Durnin and Rahaman (1967). On average, three independent measures were taken of each fold. If the second measure was not within 5% of the first, subsequent folds were measured until two folds within 5% were retained. The equation of Durnin and Rahaman (1967) was used to determine the percentage of body fat mass (BFM). Lean body mass (LBM) was determined from body mass and BFM. The subject's buoyancy was evaluated by the measurement of the hydrostatic lift (HL, Chatard et al. 1990b). The HL corresponds to the force that enables the swimmers to float when they are immersed while in forced inspiration, and was measured at the end of a maximal inspiration when subjects were floating. The subjects were in the fetal position, facing downward. A lead mass, varying in weight from 0.1 kg to 1 kg, was applied to their 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 as the HL. This method has been shown to be highly reliable ($r = 0.98$ for eight swimmers) and easy to apply (Chatard et al. 1990b).

Swimming performance

After a 15-min warm up, swimming performance was measured first in a ND situation in a 50-m pool, with each subject starting in the water, without diving. The water temperature was 26–26.5 °C. In this situation, the subjects swam alone for 400 m at a maximal velocity. Two days later, the subjects swam another maximal 400 m in a D condition, in the same lane but behind a competitive swimmer. The lead swimmer was wearing a pull-buoy to avoid the water turbulence caused by movements of the feet. For the first 200 m, the lead swimmer was instructed to follow a pace at least 3 s faster than for the first 400 m of the drafting triathletes. The pace was set for the lead swimmer by an observer walking along the side of the pool at the required speed. For the last 200 m, the triathletes could touch, if necessary, the lead swimmer's feet to indicate that he was to swim faster. The same lead swimmer was used for all of the subjects. The drafter was instructed to be as close as possible to the lead swimmer. The order of the 400-m trials could not be randomized, as the performance time in the first 200 m of the ND trial had to be established to set the pace for the first 200 m of the D trial. However, it is unlikely that a training effect could have occurred between both trials, since they were only separated by 2 days, and each subject's training was similar in volume and intensity during the day preceding each trial. However, a familiarization effect with the trial could not be ruled out.

Stroke frequency, stroke length and stroke index

During the 400-m swims, subjects were instructed to keep as constant a pace as possible. The stroke frequency, expressed as the number of complete arm cycles $\cdot$ min^{-1}, was measured for each 50 m, with a frequency meter on three complete stroke cycles, four times per 50 m. A mean value was retained for each 50 m. The stroke length was calculated by dividing the mean velocity of each 50-m swim by the mean stroke frequency of each 50 m. The stroke index was calculated by multiplying the velocity by the stroke length (Costill et al. 1985). This index assumes that at a given velocity, the swimmer who has the greatest stroke length has the most effective swimming technique and skill (Costill et al. 1985).

Expired gas analysis

Oxygen uptake ($\dot{V}O_2$, in $1 \cdot kg^{-1} \cdot min^{-1}$) was measured from the expired air collected during 20 s after the completion of the maximal 400-m front crawl swims. The method used, which was introduced by di Prampero et al. (1976), has also been described by others (Lavoie et al. 1983; Costill et al. 1985; Montpetit et al. 1988; Chatard et al. 1995). Swimmers were free from equipment. Expired gases were collected in a Douglas bag using a Daniel's breathing valve. Oxygen and carbon dioxide fractions were determined using Beckman OM 11 and LB 2 gas analyzers (Fullerton, USA) and calibrated prior to analyses with gases of known concentrations. Volumes were measured with the aid of a Tissot spirometer (Techmachine-Gymrol, Andrézieux-Bouthéon, France). This method has been found to be valid ($r = 0.97$, standard error of the estimate $= 0.238\ 1 \cdot min^{-1}$ for 20 swimmers; Chatard et al. 1995) and reliable, the reliability coefficient being between 0.92 and 0.97 (Costill et al. 1985; Montpetit et al. 1988).

Post-exercise blood lactate concentration

Two blood samples were taken at the finger extremity after the 1st and the 3rd min following the 400-m swims. Lactate concentrations were measured by an electroenzymatic method with a lactate analyzer (Cétric, Toulouse, France), using the method of Geyssant et al. (1985). Of these two samples, the highest concentration was retained. Blood lactate was considered a good means of estimating the level of exercise intensity and the anaerobic energy release (Lacour et al. 1990; Capelli et al. 1998).

Energy cost of swimming

The energy cost of swimming ($mlO_2 \cdot kg^{-1} \cdot ml^{-1}$) was calculated from the ratio of the overall metabolic power output, expressed in $mlO_2 \cdot kg^{-1} \cdot s^{-1}$, to the speed in $m \cdot s^{-1}$. In turn, the overall metabolic power was obtained from the sum of the $\dot{V}O_2$ above resting (assumed equal to $4\ mlO_2 \cdot mg^{-1} \cdot min^{-1}$) and the rate of anaerobic energy release. This was assumed to be proportional to the rate of blood lactate accumulation per unit of time, on the basis of en energy equivalent of $3\ mlO_2 \cdot kg^{-1} \cdot mM^{-1}$ (di Prampero 1981; di Prampero and Ferretti 1999).

Statistical method

The results are expressed as means (SEM). The data reported for every 50 m (swimming velocity, stroke frequency, stroke length and stroke index) were compared in D and ND conditions using a two-way analysis of variance with repeated measures. When F values were significant, individual comparisons were made with Scheffe's post-hoc test. A Student paired t-test was used to compare $\dot{V}O_2$, blood lactate, BFM and LBM in the two conditions. Correlation coefficients were calculated between all the variables using Systat programs. Statistical significance was accepted at the $P < 0.05$ level.

Results

The main characteristics of the six male triathletes are presented in Table 1. In D and ND conditions, there was no difference in $\dot{V}O_2$ [66.7 (1.7) $\mathrm{ml \cdot kg^{-1} \cdot min^{-1}}$ vs 65.6 (1.2) $\mathrm{ml \cdot kg^{-1} \cdot min^{-1}}$, respectively], however, the lactate concentrations were lower in D than in ND [9.6 (0.9) mM vs 10.8 (0.9) mM, respectively, $P < 0.01$, Table 2].

The relationship between the swimming velocity, technical parameters and the 400-m swim in D and ND conditions are presented in Fig. 1. Velocity was greater in D than in ND [1.39 (0.02) $\mathrm{m \cdot s^{-1}}$ vs 1.34 (0.02) $\mathrm{m \cdot s^{-1}}$, $P < 0.01$]. In D, a stable pace was maintained, while in ND, the velocity decreased throughout the 400-m swim ($P < 0.04$). There was no significant difference in stroke frequency [38.9 (0.7) $\mathrm{cycles \cdot min^{-1}}$ vs 40.0 (1.1) $\mathrm{cycles \cdot min^{-1}}$ in D and ND, respectively]. However, the frequency kinetics were different ($P < 0.03$). In D, the stroke frequency decreased quickly during the first 200 m, and then increased during the second 200 m. In ND, the stroke frequency decreased regularly throughout the 400-m swim. In D, the stroke length was higher than in ND [2.13 (0.06) $\mathrm{m \cdot cycle^{-1}}$ vs 2.03 (0.06) $\mathrm{m \cdot cycle^{-1}}$, $P < 0.03$]. However, the stroke length kinetic remained stable in the two different conditions. In D, the stroke index was higher than in ND [2.95 (0.03) vs 2.74 (0.02), $P < 0.02$]. The stroke index kinetic remained stable in D and decreased significantly in ND.

In D, the performance gains were related to the 400-m D velocity ($r = 0.78$, $P < 0.05$), and to the BFM ($r = 0.99$, $P < 0.01$), while the stroke index was also related to BFM ($r = 0.78$, $P < 0.05$). Faster and leaner swimmers thus achieved greater performance gains and a higher stroke index. No relationship was found between the performance gains and the variations in stroke frequency and stroke length.

Discussion

The present study shows that when drafting in swimming:

1. There is no difference in $\dot{V}O_2$, while the blood lactate concentration is lower than in ND conditions.
2. The performance, stroke length and stroke index increase while the stroke frequency remains unchanged.
3. Finally, the performance gains are related to the swimming velocity, and the stroke index is related to the triathletes' BFM.

Drafting and the energy cost of swimming

The performance gains and the metabolic responses observed in the present study were in accordance with

Table 1 Characteristics of the six male triathletes who acted as subjects for this study. (*HL* Hydrostatic lift, *FBM* body fat mass, *LBM* lean body mass)

Subject characteristics							Training characteristics		
Subject	Age (years)	Body mass (kg)	Height (cm)	HL (kg)	BFM (%)	LBM (kg)	Swimming ($\mathrm{km \cdot week^{-1}}$)	Cycling ($\mathrm{km \cdot week^{-1}}$)	Running ($\mathrm{km \cdot week^{-1}}$)
1	25	62.2	169	2.1	9.9	56.1	20	350	50
2	21	69.2	182	2.4	9.4	62.7	18	300	25
3	30	73.6	180	0.5	9.1	66.9	18	280	40
4	23	65.3	178	1.9	9.9	58.9	16	200	40
5	26	71.3	175	2.8	13.7	61.5	20	350	60
6	23	74.0	181	1.9	8.5	67.7	20	350	50
Mean	24.7	69.3	177.5	1.9	10.1	62.3	19	305	44
SEM	1.3	1.9	2.0	0.3	0.8	1.8	0.7	24.3	4.9

Table 2 Mean (SEM) values obtained in drafting and non-drafting conditions. ($\dot{V}O_2$ Oxygen consumption, *La* lactate concentration, *v* swimming velocity, *SI* stroke index, *SF* stroke frequency, *SL* stroke length)

Condition	$\dot{V}O_2$ ($\mathrm{ml \cdot kg^{-1} \cdot min^{-1}}$)	La (mM)	v ($\mathrm{m \cdot s^{-1}}$)	SI ($\mathrm{m^2 \cdot s^{-1}}$)	SF ($\mathrm{cycles \cdot min^{-1}}$)	SL ($\mathrm{m \cdot cycle^{-1}}$)
Non-drafting	65.6 (1.2)	10.8 (0.9)	1.34 (0.02)	2.74 (0.02)	40.0 (1.1)	2.03 (0.06)
Drafting	66.7 (1.7)	9.6 (0.9)*	1.39 (0.02)*	2.95 (0.03)*	38.9 (0.7)	2.13 (0.06)*

*$P < 0.05$: Significant difference between drafting and non-drafting conditions

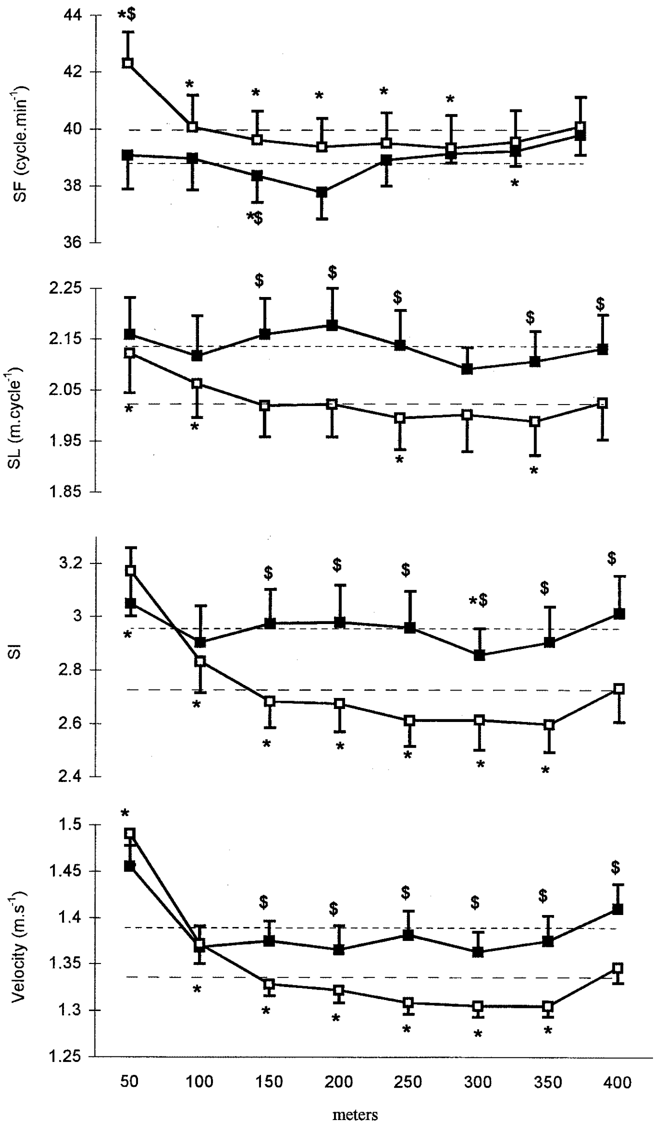

Fig. 1 Differences and variations in swimming velocity, stroke index (*SI*), stroke length (*SL*) and stroke frequency (*SF*) during the drafting (*filled squares*) and non-drafting (*open squares*) 400-m swim. $^{\$}P < 0.05$: differences in drafting versus non-drafting conditions; $*P < 0.05$: differences between each 50-m value and mean 400-m in drafting (- - -) and non-drafting conditions (—)

other observations concerning drafting swimming (Chatard et al. 1998). The data allow one to calculate the energy cost of swimming in D and ND conditions, as described in the Methods section. The net $\dot{V}O_2$ was 1.045 (0.029) $l \cdot kg^{-1} \cdot s^{-1}$ and 1.03 (0.022) $l \cdot kg^{-1} \cdot s^{-1}$, the rate of lactate accumulation 0.030 (0.012) $mM \cdot s^{-1}$ and 0.0328 (0.003) $mM \cdot s^{-1}$, thus yielding a rate of anaerobic energy release from lactate equivalent 0.09 (0.037) $mlO_2 \cdot kg^{-1} \cdot s^{-1}$ and 0.10 (0.009) $mlO_2 \cdot kg^{-1} \cdot s^{-1}$ for the D and ND conditions, respectively. So the overall metabolic power output can be calculated as $1.03 + 01 = 1.13$ $mlO_2 \cdot kg^{-1} \cdot s^{-1}$ and $1.05 + 0.09 = 1.14$ $mlO_2 \cdot kg^{-1} \cdot s^{-1}$ for the D and ND conditions, respectively. The energy cost per unit of distance can be calculated by dividing these values by the average velocity, 1.39 $m \cdot s^{-1}$ and 1.34 $m \cdot s^{-1}$ for the D and ND conditions, respectively. The result is 0.82 (0.033) $ml \cdot kg^{-1} \cdot m^{-1}$ and 0.84 (0.019) $ml \cdot kg^{-1} \cdot m^{-1}$, respectively, so the ratio between D and ND conditions turns out to be 0.976. The effects of D on the energy cost of swimming the front crawl can now be calculated. Indeed, the energy cost of swimming ought to increase approximately with the square of the velocity (Toussaint et al. 1988; Wakayoshi et al. 1995; Ogita et al. 1996). Thus, in the D condition it ought to be $1.39^2/1.34^2 = 1.076$ times larger than in the ND situation, since the velocity in the former was 1.39 $m \cdot s^{-1}$, as opposed to 1.34 $m \cdot s^{-1}$ in the latter. On the contrary, the experimental data show that at 1.39 $m \cdot s^{-1}$, the energy cost of swimming was $0.82/0.84 = 0.976$ times that at 1.34 $m \cdot s^{-1}$. Hence, drafting reduced the energy cost from 1.076 to 0.976 (i.e., by about 10%). It is now interesting to compare the calculated reduction in energy cost with the results of Chatard et al. (1998), who have shown that passive drag is reduced by drafting when measured in the same swimming conditions, behind a leader using a pull-buoy. The data reported in Fig. 1 of this paper, and the corresponding regressions show the drag at 1.39 $m \cdot s^{-1}$ in D conditions and at 1.34 $m \cdot s^{-1}$ in ND conditions. The results are 38.4N and 44N, respectively. So the corresponding reduction of the passive drag is $38.4/44 = 0.87$. The resulting reduction of 13% is close to that of the 10% calculated above for the energy cost of swimming. It is also close to the 10% drag reduction measured at the same velocity for female triathletes swimming behind a leader using a 2- or a 6-beat kick (Millet et al. 2000).

Drafting and stroking parameters

In D swimming, the performance and the stroking parameters (i.e., stroke length and stroke index) increased, while the stroke frequency remained unchanged. On the contrary, in the ND condition, the stroke frequency, and stroke length decreased throughout the 400-m swim. This phenomenon was probably due to the fatigue developed, as already demonstrated by Craig et al. (1985). This is supported by the greater lactate concentrations measured at the end of the ND condition, indicating a greater use of anaerobic metabolism. In the D condition, the greater swimming velocity is associated with a greater stroke length for a similar stroke frequency, and the $\dot{V}O_2$ suggests a higher efficiency that is probably due to the decrease in the water resistance (Chatard et al. 1998).

In the D conditions, no correlation was found between the performance gain and the variation of the stroking parameters. However, the pace and the stroking parameters were more stable than in ND conditions. These data may explain the greater metabolic efficiency found in the present study. Indeed, for a given velocity, changes in stride frequency and stride length have been shown to increase the energy cost of running (Cavanagh and Williams 1982; Martin and Morgan 1992). Chollet et al. (1997), studying 442 male swimmers (including 40 swimmers competing at an international level), demonstrated that the best swimmers were characterized by their capacity to maintain a higher consistency of technique and velocity throughout the course of the race than their counterparts. In the same way, improvements in stroke parameters such as the stroke length, have also been observed in drafting kayaking (Gray et al. 1995).

The correlations between the performance gains, the velocity, the BFM and the stroke index indicate that faster and leaner swimmers are the most advantaged by D conditions. Chatard et al. (1998) suggested that faster swimmers are better swimmers than their counterparts, and thus could benefit more from the D situation because of their better swimming ability. This observation is supported by Rundell (1996), who showed that some speed skaters are more effective drafters than others. The higher gain in performance observed for leaner subjects is consistent with the drag variations measured by Chatard et al. (1998). Indeed, swimmers with a greater skinfold thickness tend naturally to adopt a more horizontal position because of a better floating position, and thus have a lower body drag than leaner subjects (Pendergast et al. 1977).

In summary, the results of this study demonstrate that drafting during swimming improves performance by decreasing the overall energy cost of swimming (by 10%). Drafting also contributes to stabilizing the stroke parameters such as stroke frequency and stroke length.

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