國立體育學院九十三學年度研究所博士班入學考試試題

體育運動論文評論（生物力學組）　（本試題共12頁）

※注意:答案一律寫在答案卷上，否則不予計分

1. 請詳細閱讀所附之論文，並列出本論文之主要內容。(20%)

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ORIGINAL RESEARCH

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Triathlon Wet Suit and Technical Parameters at the Start and End of a 1500-m Swim

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The aim of this study was to determine the effect of wearing a triathlon wet suit on the technical parameters of the front crawl stroke. Eight highly trained male triathletes were filmed with underwater camcorders during two 1500-m swim tests: one with a wet suit (WS) and the other with a standard suit (SS). Two conditions were considered: Condition I (C_I) and Condition XV (C_{XV}), representing the 1st and the 15th 100-m, respectively. Views were synchronized and digitized using kinematic analysis software (Schleihauf, 1994) to obtain 3-D coordinates of the anatomical landmarks of the body. Results showed that the wet suit and duration of the exercise significantly influenced stroke parameters. The swim with WS was characterized by greater stroke length and a progressive increase in stroke frequency, resulting from a more extended elbow position during the stroke and from a decrease in the absolute and relative times of the propulsive phase. These changes indicated more efficient upper limb action. The duration of exercise modified the swim with WS and SS. The loss of velocity observed in C_{XV} was related to a decrease in stroke length, or more precisely a reduction in lever arm length during the aquatic phase, insufficiently offset by a slight increase in stroke frequency. These two motor responses, a less extended elbow position and a stroke frequency increase, emerged as an easier motor solution for coping with the effect of fatigue. This solution could be regarded as an adaptation to the duration of the exercise.

Key Words: swimming technique, hand trajectory, fatigue, buoyancy

Introduction

The triathlon event begins with an open water swim representing 10 to 15% of the total time of the race (Lehenaff, 1997). However, this short first event determines how the triathlon unfolds because it provides a first selection among competitors.

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This is especially important in draft-legal competitions as it allows athletes to group into packs during the cycling event.

During the swim, in water at a temperature below or equal to 20 °C, wearing a neoprene wet suit is mandatory to protect the body from the risk of hypothermia. Offering more than thermal protection, the wet suit increases swimming speed by up to 10% (Lowdon, McKenzie, & Ridge, 1992). The gain in performance is mainly explained by enhanced bouyancy. This is related to the low specific gravity of the suit, inducing a decrease in water resistance encountered by the swimmer by virtue of a smaller frontal area (Toussaint, Bruinink, Coster, et al., 1989). The wet suit, with its smooth coating, also decreases friction drag during the swim (Toussaint et al., 1989), giving the athlete greater gliding aptitude. These differences in body position and glide in the water can destabilize swimmers who are not accustomed to this type of swim. For example, in the study by Chatard, Xénégas, Selles, Dréano, and Geyssant (1995), high-level swimmers who had never worn a wet suit found it difficult to expend maximum effort when wearing one.

It seems clear that changes in glide aptitude and body position in the water could also modify some of the technical parameters of the front crawl stroke. In two studies comparing the swim with and without a wet suit, some authors have observed an increase in stroke rate (Chatard et al., 1995; Perrier & Monteil, 2002) and distance covered per stroke (Perrier & Monteil, 2002) during the swim with a wet suit. However, no studies have focused on the spatial and temporal phases of the aquatic hand trajectory during a swim with a neoprene wet suit.

Since the essential propulsion is provided by the upper limbs during long distance swimming (Counsilman, 1968), it seems important to determine whether the pattern of the swim, classically developed with the standard suit, will be altered or not by body buoyancy and glide changes with the wet suit.

Furthermore, considering the great distance covered during the triathlon swim, it will be important to study whether the duration of the exercise could also have an impact on these possible alterations. The answer to these questions may be interesting with respect to transferring technical acquisitions from training situations to competition events.

The purpose of the present study, therefore, was to determine whether wearing a wet suit with increased buoyancy would modify the stroke pattern of 8 triathletes at the beginning and end of a 1500-m front crawl swim. In this way we hoped to determine the influence of wet suit effects on the duration of the test.

Methods

The study population consisted of 8 trained male triathletes, from French national to international levels. All participated in the study on a voluntary basis. Their general characteristics are summarized in Table 1.

Tests consisted of two complete standardized 1500-m front crawl swims with a complete wet suit (WS) and a standard suit (SS), randomly separated by 6-day intervals. Tests took place in a 50-m indoor swimming pool, at 26 °C. Participants were instructed first to swim at the pace of an Olympic distance competitive triathlon, and second to maintain stable velocity after the first 100 m without diving. The same triathlon wet suit model (Aquaman®, La Garenne-Colombe, France) was used for the test in 3 sizes according to the anthropometrical characteristics of each participant. This model was chosen for its maximum thickness as allowed by

Table 1 General Characteristics of the 8 Triathletes (mean ± *SD*)

Triathletes	Age (yrs)	Ht (m)	Mass (kg)	Training Triath. (hr/wk)	Training Swim (hr/wk)	Training Swim (km/wk)	Best time in 1500-m (min)
1	24	1.87	76	20	4	10	00:19:40
2	28	1.81	73	20	6	18	00:21:20
3	24	1.72	79	20	5	13	00:20:46
4	23	1.85	80	18	6	15	00:19:30
5	20	1.69	58	15	4	10	00:22:00
6	20	1.92	74	12	5.5	15	00:18:30
7	32	1.82	75	20	4	12	00:17:55
8	25	1.83	74	20	6.5	15	00:17:15
Avg	24.8	1.81	73.6	18.1	5.1	13.5	00:19:37
SD	3.7	0.1	6.8	3	1	2.8	00:01:41

Triathlon Federation rules. The suit was made of smooth neoprene, 5 mm thick on the trunk and lower limbs and 1.5 mm on the upper limbs. The complete wet suit covered the entire body except for the feet, hands, and head.

Data acquisition during the test involved filming the triathletes with two fixed underwater camcorders operating at 30 Hz and providing sagittal and frontal views of the motion. The frontal and sagittal cameras recorded the swimmer' complete arm cycle. A third out-of-water camera located at the middle of the pool, perpendicular to the swimmer's direction, was used to verify the regularity of the studied arm stroke in comparison with the previous strokes of the same 50-m length.

Views were synchronized and digitized frame by frame using kinematic analysis software (Schleihauf, 1994) in order to obtain 3-D coordinates of 22 anatomical landmarks of the body. Their trajectories were fitted using a "least square polynomial moving average" routine. The selected smoothing factor is 2, causing a curve fit with 7 points at a time. The accuracy and reliability of this method have been demonstrated (Montei, Chèze, Masset, & Rouard, 1996; Lauder, Dabnichki, & Bartlett, 2001).

Measurements were taken during the first (Condition I) and last (Condition XV) 100-m of the 1500-m, with (WS) and without (SS) wet suits in order that the effects of the wet suit during a long-duration exercise could be studied. First, main parameters such as swimming time and buoyancy related to the wearing of a wet suit were determined. Buoyancy was estimated in a static situation by measuring the hydrostatic lift (HL) corresponding to the force that enables a swimmer to float. This method, described by Chatard, Collomp, Maglischo, and Maglischo (1990a), consists of adding some weight to the emerging part of a swimmer's back, the swimmer being in the fetal position with maximum air intake.

In order to analyze the evolution of determinant parameters related to swimming velocity, we examined stroke length, frequency, and velocity. Stroke fre-

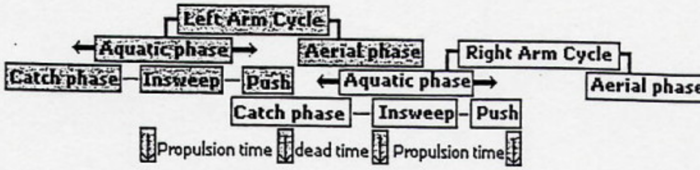

Figure 1 — Representation of the stroke structure.

quency was expressed as the number of complete arm strokes per minute. Stroke length corresponded to hip displacement during one stroke. Stroke velocity was the product of stroke frequency and stroke length.

To describe the swimming technique of the triathletes and to quantify their swimming skill, we calculated the coordination index and the stroke index. The coordination index was defined as the ratio of dead time (time without propulsive action) over the total time of the stroke (Chollet, Challies, & Chatard, 1999) (Figure 1). From this coordination index we identified two phases (insweep and push) as propulsive, whereas the aerial and catch phases were more related to preparation of the stroke. The stroke index was the product of stroke velocity and stroke length (Costill, Kovaleski, Porter, et al., 1985).

In order to study the temporal structure of the cycle, we measured the absolute and relative durations of the different phases of the stroke. According to Maglischo, Maglischo, Higgins, et al. (1986), the aquatic part of the stroke can be divided into three phases from the frontal plane of the hand's trajectory: the catch, from entry into the water to the most external point; the insweep, from the most external to the most internal point; and the push, from the most internal point until exit from the water.

Furthermore, the vertical and lateral amplitudes of each phase determined from the 3-D aquatic trajectories of the hand were studied in order to characterize the stroke spatially. These parameters were studied for a representative arm stroke of the swim chosen from the out-of-water camcorder. The selection criteria were the equality of stroke frequency values between the studied arm stroke and the average of the previous strokes collected by the camcorder.

Concerning statistical analyses, for all the studied parameters we calculated mean and standard deviation values. In order to compare the effects of the wet suit and of the duration of exercise, we applied the Wilcoxon signed rank test. Correlation coefficients were calculated to describe the relationships between the different parameters. For all the statistical analyses, the level of significant difference was set at 0.05.

Results

Wearing a wet suit improved hydrostatic lift, from 17.9 ± 8.8 N with SS to 46.9 ± 6.8 N with WS, $p < 0.01$, while swimming time decreased significantly, from 1294 ± 142 s with SS compared to 1214 ± 123 s with WS, $p < 0.01$.

As for the effect of WS on the technical parameters of the swim in Conditions I and XV, the wearing of a wet suit indicated kinematical stroke differences when compared to the standard swimming suit (Table 2). A greater stroke index

Table 2 Stroke Parameters, Technical Data, Temporal and Amplitude Parameters for the 8 Triathletes Wearing SS and WS During Each Condition of the Test

	Condition I (first 100 m)				Condition XV (last 100 m)			
	Standard suit		Wet suit		Standard suit		Wet suit	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Stroke velocity ($m \cdot s^{-1}$)	1.26	0.15	1.37	0.13**	1.15	0.11†	1.24	0.11** †
Stroke frequency ($cycle \cdot min^{-1}$)	35.8	3.2	36.7	2.4	37.1	2.4	38.9	3.3** †
Stroke length ($m \cdot cycle^{-1}$)	2.12	0.2	2.24	0.19**	1.87	0.23††	1.93	0.24** ††
Stroke index ($m^2 \cdot s^{-1}$)	2.69	0.5	3.07	0.5**	2.16	0.45††	2.40	0.49** ††
Coordination index (% dead time/cycle time)	–17.7%	8%	–20.6%	6%	–12.6%	8%†	–18.4%	1%
Catch phase time (s)	0.70	0.1	0.69	0.1	0.65	0.1	0.63	0.1†
Propulsive phase time (s)	0.56	0.05	0.50	0.05**	0.60	0.06	0.53	0.08**
Catch phase (% aquatic phase)	55%	5%	57.7%	4%*	51.6%	4%	54.1%	6%†
Propulsive phase (% aquat. phase)	45%	5%	42.3%	4%*	48.4%	4%	45.9%	6%†
Insweep phase amplitude (m)	0.27	0.09	0.30	0.11	0.17	0.05††	0.18	0.07††
Deepest point of trajectory (m)	0.72	0.08	0.81	0.13*	0.61	0.05††	0.67	0.07* ††

Note: Significant differences: Between the two swimming situations (WS and SS): $^*p < 0.05$, $^{**}p < 0.01$;
Between Conditions I and XV: $^{\dagger}p < 0.05$; $^{\dagger\dagger}p < 0.01$.

was obtained, resulting from a higher stroke swimming velocity and stroke length. Stroke frequency increased slightly at the beginning of the 1500-m and significantly at the end. The relative duration of the aquatic part of the stroke changed, with a tendency to spend more time on the catch phase than on propulsive phases. Vertical amplitude of the hand trajectory was significantly greater (Figures 2 and 3).

The WS effect on test duration was as follows: Whatever suit was worn, Condition XV was characterized by a decrease in swimming velocity related to a reduction in stroke length (Table 2). As a result, stroke index was also diminished. Stroke frequency increased slightly with the standard suit and significantly with the wet suit. The relative duration of the catch phase tended to decrease at the expense of the propulsive phases. Vertical and lateral amplitudes of the aquatic hand's trajectory were significantly shortened (Figures 4 and 5). The coordination index was significantly higher only with the standard suit (Figure 6).

Discussion

The discussion will first focus on the effect of a triathlon wet suit on the kinematic parameters of the front crawl stroke under two conditions: the beginning and the end of a 1500-m test. Then these conditions will be compared for each suit (wet and standard) in order to reveal fatigue effects related to the duration of the exercise.

Wet Suit Effects

For the 8 triathletes, wearing a triathlon wet suit increased static buoyancy +262% and decreased swimming time by 6.5% over the 1500-m. Performance gains observed in the present study were in keeping with other findings regarding wet suit effects (Chatard et al., 1995; Parsons & Day, 1986). However, the increase in buoyancy obtained in this study was 27% lower than that in Chatard et al.'s study (1995). This could be due to the difference in thickness, especially on the upper limbs of the wet suit.

With the wet suit, improvements in performance were related to greater stroke length and a progressive increase in stroke frequency, leading to more efficient arm action. Indeed, the stroke index was increased[1] whereas stroke duration tended to decrease. This reduction was related to a diminution of the absolute and relative times of the propulsive phases. Greater efficiency was also indicated by the invariance in coordination index. It should be noted that these coordination index values identified a catch-up swim characterized by a considerable dead time of 17.7 to 20.6% of the total time of the stroke. This style lengthens the body by maintaining an arm in its forward extension. Such a position induces a gliding attitude, which can be beneficial to triathletes in that it reduces the energy cost of swimming and conserves more energy for the cycling and running events.

This invariance of the coordination index also discredited the hypothesis of better leg kicks during the swim with the wet suit. Indeed, no more time was given for the lower limb action to use the upper-limb phase without propulsion (Chollet

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[1] The example of the swim with wet suit shows that the stroke index could be a partial indicator of the propelling efficiency of the arms, but not for the swimming skill parameter. Indeed, the swimming skill of the triathletes did not change between the two tests whereas the stroke index was strongly increased during the swim with a wet suit (14%).

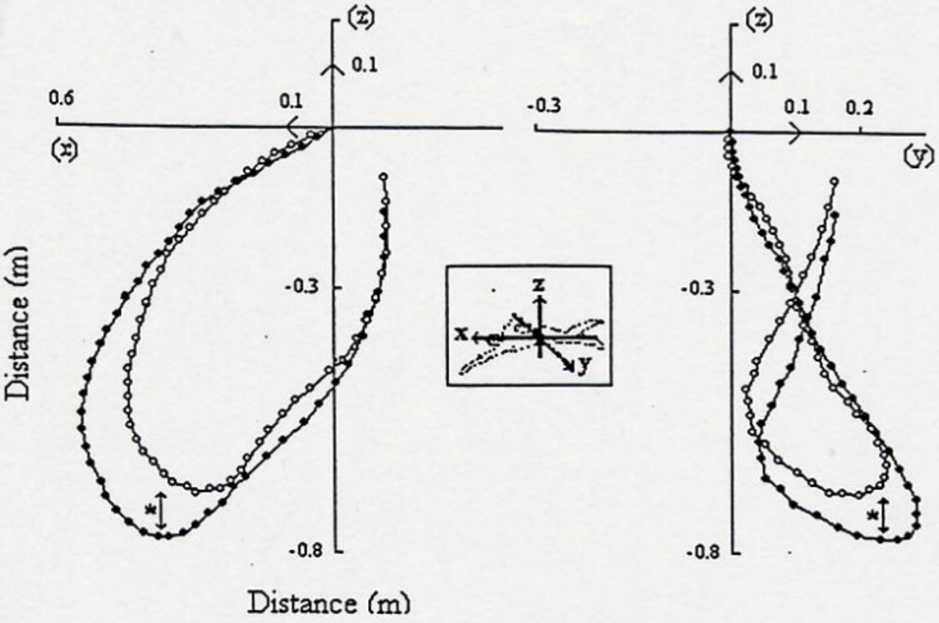

Figure 2 — Wet suit effects on the average left hand trajectory in the sagittal and frontal planes over the *first* 100 m (○ ○ Standard Suit; ● ● Wet Suit). *Significant difference, $p < 0.05$, between the two situations.

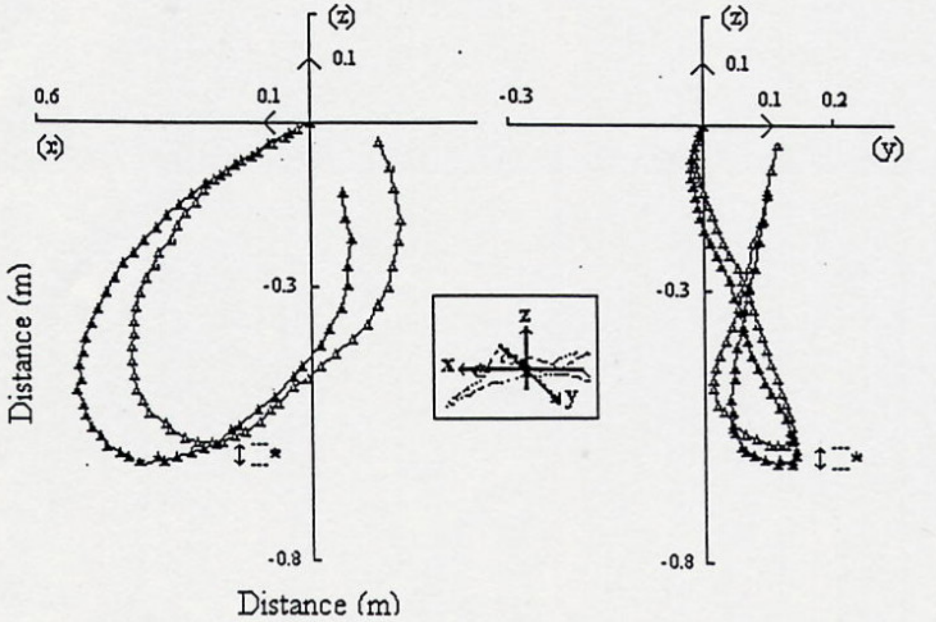

Figure 3 — Wet suit effects on the average left hand trajectory in the sagittal and frontal planes over the *last* 100 m (Δ Δ Standard Suit; ▲ ▲ Wet Suit). *Significant difference, $p < 0.05$, between the two situations.

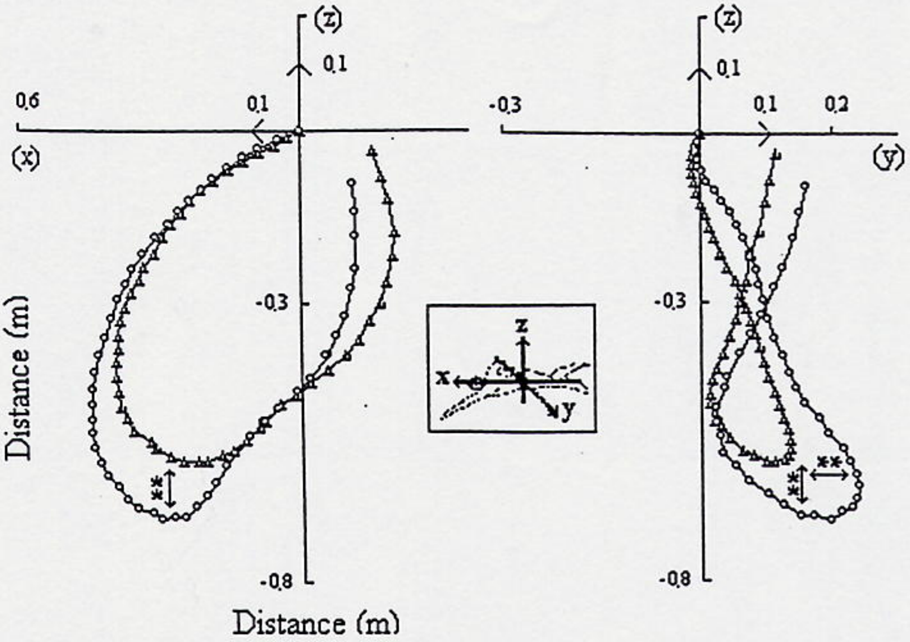

Figure 4 — Differences between Condition I (first 100 m) and Condition XV (last 100 m) on the average left hand trajectory in the sagittal and frontal planes wearing a Standard Suit (○ ○ Condition I; Δ Δ Condition XV). **Significant difference, $p <$ 0.01, between the two conditions.

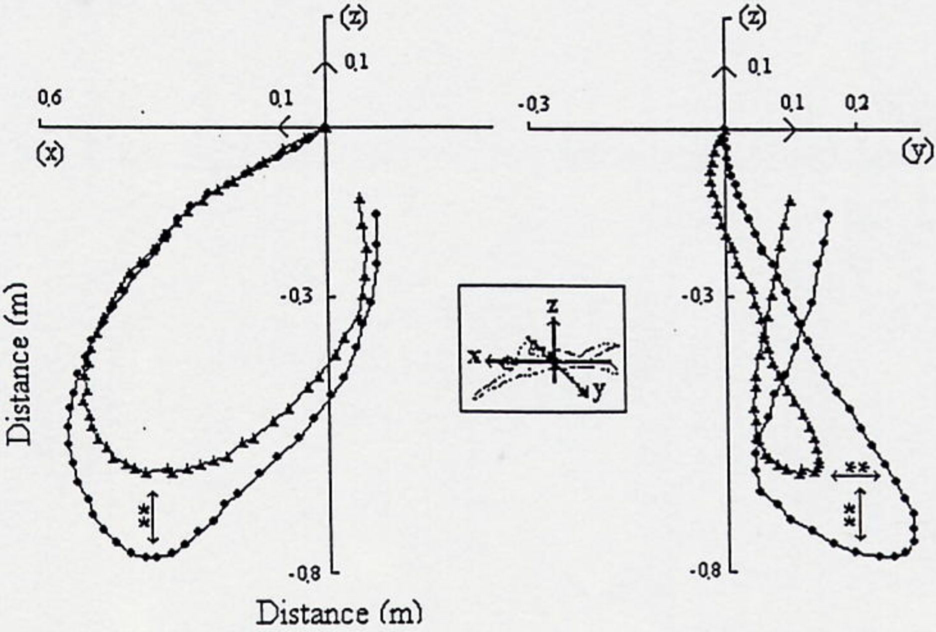

Figure 5 — Differences between Conditions I and XV on the average left hand trajectory in the sagittal and frontal planes wearing a Wet Suit (● ● Condition I; ▲ ▲ Condition XV). **Significant difference, $p < 0.01$, between the two conditions.

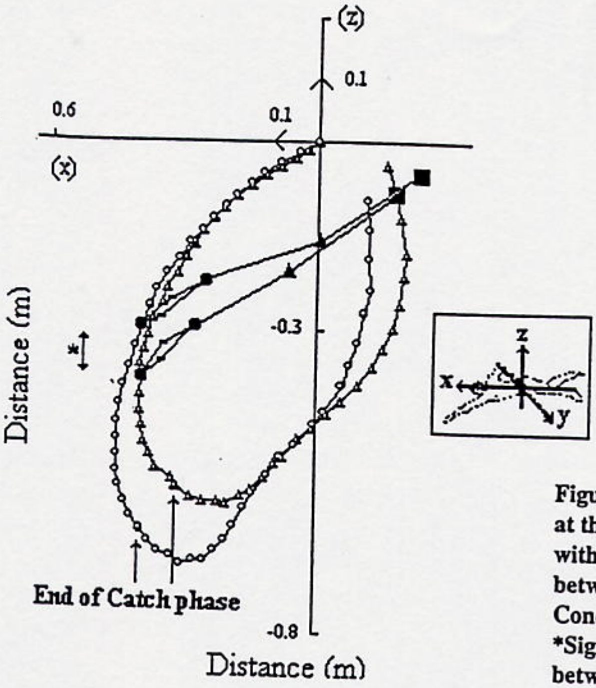

Figure 6 — Positions of the left arm at the end of right arm propulsion with a Standard Suit. Differences between Conditions I and XV (○ ○ Condition I; Δ Δ Condition XV). *Significant difference, $p < 0.05$, between the two conditions.

et al., 1999). In addition, as the wet suit caused the lower limbs to rise toward the surface of the water, their contribution to total propulsion seemed secondary.

This added buoyancy implied a specific aquatic hand trajectory characterized by an increase in its vertical amplitude. This increase suggested that the swimmers presented more lever arm action during the aquatic phase of their stroke, confirming the positive linear relationship between the level of buoyancy and depth of hand trajectory found in a previous study (Chatard, Lavoie, Bourgoin, & Lacour, 1990b). It should be noted that the deepest hand trajectory point was reached during the insweep phase, emphasizing the importance of this phase with regard to swimming propulsion. The more extended elbow position, indicated by the extra lever arm, could also be partially attributed to the thickness of the neoprene and structure of the wet suit, as the swimmers demonstrated less mobility of the elbow joint.

Fatigue Effect

Compared with the beginning of the test, the end was characterized by numerous kinematical stroke variations related to fatigue which usually appeared at the end of the two swimming conditions.

The first change concerned swimming velocity, which decreased by 9% between Conditions I and XV. This loss of velocity was characterized by a significant decrease of 12 to 14% in stroke length which was insufficiently offset by a slight increase of 3.5 to 6% in stroke frequency. Consequently, the stroke index was significantly lower at the end of the test. This could be attributed to a fatigue effect (as previously demonstrated by Craig, Skehan, Pawelczyk, & Boomer, 1985) and to changes in the organization of spatiotemporal stroke parameters. This point was confirmed by the evolution of the ratio between catch and propulsive phase times. Indeed, at the end of the 1500-m, the relative time of the propulsive phases increased at the expense of one of the catch phases.

With the standard suit, triathletes seemed to organize their technique by spending more time in propulsion to offset a lack of efficiency. This hypothesis was also supported by the higher coordination index observed at the end of the test, indicating a decrease in dead time between arm actions. The upper limbs are probably unable to generate enough strength to produce the same body glide as at the beginning of the swim. Wearing a wet suit, the invariance of the coordination index could be explained by the gain in buoyancy being sufficient to maintain body glide in spite of a possible decrease in strength of the upper limbs. Indeed, the diminution of lateral and vertical amplitudes of the aquatic hand trajectory, indicating that the upper limb was less extended, could confirm this loss of strength. It could therefore be hypothesized that triathletes cannot swim with the same lever arm throughout the 1500-m. This could be confirmed by the slight increase in stroke frequency.

Such results are in keeping with a study by Fomichenko (1971) conducted on sprint swimmers in which it was concluded that the duration of the active phase increased whereas the duration of the passive phase decreased under the impact of fatigue. Furthermore, Fomichenko suggested that one index of swimming mastery could be the swimmer's ability to withstand fatigue with the help of a change in the phasic structure of the cycle by increasing the duration of the pull phase. The two specific motor responses observed at the end of the 1500-m, a decrease in lever arm action and an increase in stroke frequency, emerged as an easier solution for coping with fatigue and therefore adaptating to the duration of the exercise.

In conclusion, the main results of the present study indicate that wearing a wet suit increases buoyancy, enhances swimming velocity, and improves the propulsive efficiency of the upper limbs. Indeed, this swim was characterized by a greater stroke length, an increase in stroke rate, and a more extended elbow position during the aquatic stroke. Second, some changes occurred at the end of the 1500-m and could be related to fatigue. These adaptations to the duration of the swim led to an increase in stroke frequency and a reduction of lever arm action during the propulsive phase, and seemed to be related to a decrease in muscular strength. From the findings of this study, it may be suggested that swim training products which increase buoyancy, such as "pull kicks" or "pull buoys," should be used appropriately during training as they could influence technical stroke parameters.

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