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Morning vs. Evening Maximal Cycle Power and Technical Swimming Ability

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Abstract. Deschodt, Veronique J., and Arsac, Laurent M. Morning versus evening maximal cycle power and technical swimming ability. *J. Strength Cond. Res. 18(1):149–154. 2004.*—The aim of this study was to observe diurnal influences on maximal power and technical swimming ability at three different times (8 AM, 1 PM, and 6 PM). Prior to each test, tympanic temperature was taken. Maximal power was analyzed by cycle tests. Stroke length, stroke rate, hand pattern, and swimming velocity were recorded between the 20th and the 28th m of the 50-m freestyle. Temperature varied ±0.4° C between morning and evening. Concomitantly, maximal power (+7%) and technical ability (+3% in stroke length, +5% in stroke rate and changes in underwater hand coordinates) were greater in the evening. The present study confirms and specifies diurnal influences on all-out performances with regard to both maximal power and technical ability. Thus, when swimmers are called upon to perform at a high level in the morning, they should warm up extensively in order to "swamp" the diurnal effects of the morning.

Key Words. diurnal variations, force velocity, cycling ergometry, swimming, video analysis

Introduction

In high-intensity exercises, maximal muscle strength at a given velocity (i.e., power) and technical ability are factors of great importance for performance. Previous studies have largely demonstrated diurnal variations in the performance of physical activities. However, results regarding brief maximal exercise are less consistent with this concept of diurnal variations. For example, Bernard et al. (5) found a 7% higher value for afternoon multi-jumping performances compared to morning performances, whereas the same subjects varied little in 50-m running times between morning and evening. Moreover, for longer exercises (30-second Wingate test), different results have been obtained according to the population tested (25, 28). Nevertheless, in all of these studies, diurnal temperature variations were found, reflecting the existence of body clock activity subsumed by the suprachiasmatic nuclei (20). As emphasized by Reilly and Marshall (30), the amplitude of circadian rhythms increases with the complexity of motor tasks. Thus, it would be of interest to analyze diurnal variations not only on whole performance but also with regard to its different components such as maximal power and technical ability.

We hypothesized that diurnal changes might appear in these components, thus explaining the variations in whole performance. To test this hypothesis, 11 subjects performed a force-velocity test at 3 different times on separate days in order to determine maximal power and a 50-m freestyle swim in order to analyze their technical ability. We used a force-velocity test with the lower limb on a cycle ergometer because it is accurate and reproducible. Swimming is an activity requiring a very high technical level, and top-level freestyle swimmers produce a specific underwater pattern of action (14). The ability to achieve a wide amplitude of movement not only on the first part of the underwater stroke on the antero-posterior axis, but also on the middle part of the stroke on the vertical and lateral axes, is necessary to attain a high level of performance in sprint swimming (23). Therefore, reaching high velocities during front crawl swimming obviously requires a high technical ability. Thus, the capacity to swim at maximal velocity while producing an optimal underwater arm stroke was chosen here to define technical ability.

Methods

Experimental Approach to the Problem

Two tests, a cycle ergometer in the laboratory and a 50-m freestyle swim at maximal velocity, were performed in random order at 3 distinct times of the day (8 AM, 1 PM, and 6 PM) to evaluate maximal power and technical ability. The order of the 3 sessions (morning, afternoon and evening) was randomized with a minimum of 15 hours between each one. To confirm the existence of standard diurnal variations, tympanic temperature was taken at the ear prior to each standardized warm-up. Before force-velocity experiments, subjects were familiarized with the testing procedure (cycle ergometer). Strenuous physical activity was prohibited on the day before either test and during the day prior to the afternoon and evening tests.

Subjects

Eleven swimmers (6 women and 5 men) who participate in regular swimming competitions at regional and national levels gave their informed consent to take part in this study. All subjects were members of the university swimming team. The best performance in the 100-m freestyle by the women was 63.81 ± 4.12 seconds and by the men was 56.02 ± 3.01 seconds. Their mean age was 19 ± 1.3 years; mean height was 1.72 ± 0.07 m. On the basis of their answers to the Horne and Ostberg self-assessment questionnaire measuring "morningness" and "eveningness" in human circadian rhythms (19), all 11 subjects were identified either as "moderately morning types" (n = 2) or as neither type (n = 9). When they first arrived in the laboratory, subjects were asked about their training habits. Two swimmers presented specific habits, usually training between 6 AM and 9 AM, unlike the others, who were used to training in the afternoon or early evening. Throughout the study, all subjects were instructed to be adequately hydrated and not to eat for 3 hours before any test.

Cycling Ergometer Measurements

Because its reproducibility is well established (1) and also because jumping and cycling tests are the most widely used to assess maximal power, we obtained maximal power on a properly calibrated cycle ergometer. A friction-loaded cycle ergometer was instrumented with a strain gauge and an incremental optical encoder as described elsewhere (1). Briefly, both the frictional load and the acceleration balancing load (21) were accurately measured during the acceleration phase of 2 successive all-out cycling exercises performed from a standing start and interspersed with a 10-minute recovery period. In a randomized order, one test was performed against a 30 $g \cdot kg^{-1}$ friction load (plus flywheel inertia) and the other one against a 60 $g \cdot kg^{-1}$ friction load (plus flywheel inertia). Instantaneous force (friction plus inertia), velocity, and power were averaged over each downstroke period, thus providing as many F-V-P combinations as downstrokes. Velocity-power combinations served to draw individual V-P relations that were fitted to third-order polynomial functions (Figure 1). The maximal power (Pmax, in watts) was determined mathematically from the apex of the function and the corresponding optimal pedaling velocity (Vopt) was also noted.

The work output (in joules) corresponding to the first 20 pedal revolutions completed in 5.72 ± 0.92 seconds at 30 $g \cdot kg^{-1}$ and in 5.67 ± 0.92 seconds at 60 $g \cdot kg^{-1}$ was calculated.

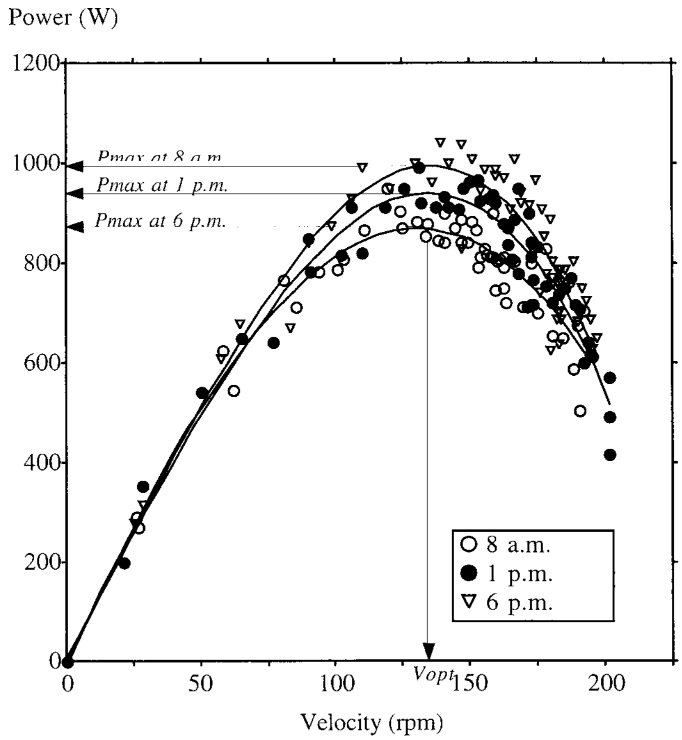

FIGURE 1. Typical velocity-power relations obtained with two friction loads at 8 AM, 1 PM, and 6 PM.

Technical Ability Measurements

To analyze technique, underwater strokes were recorded during the 50-m freestyle. To avoid changes linked to the fatigue effect, only strokes produced between the 20th and the 28th m of the 50 m were analyzed. Reproducibility was tested (a) by comparing two strokes at different distances of the 50 m for each of the subjects and at each tested time, and (b) by achieving a test-retest digitizing procedure. Intraindividual stroke differences were never significant ($p > 0.05$). The test-retest digitizing procedure shows that the greatest error value reaches a maximal value at about 2% for the anterior displacements of the hand, especially at the beginning of the stroke.

A video-camcorder (HI8 EVO 150 TR Sony, 24 Hz; Paris, France) enclosed in a waterproof box was used to record lateral views of the underwater arm strokes. For all subjects, only left underwater strokes were analyzed. On each frame, estimated locations of left wrist and left hip joints and a fixed background point on the pool wall were semimanually digitized (33). The location where the hand entered the water was taken as a reference point with coordinates (0, 0, 0). The underwater movement of the left wrist was broken down into 3 phases defined as follows:

- The glide phase: corresponding to the trajectory from the hand's entry into the water to the most frontal position of the hand (F in Figure 2).
- The pull phase: corresponding to the trajectory from F, where backward movement begins, to the deepest position of the hand (D in Figure 2).
- The push phase: corresponding to the trajectory from D to the hand exiting the water. The backward movement of the hand was symbolized by the most posterior coordinate of the hand (B in Figure 2).

The left hip velocity along the antero-posterior axis was obtained from the digitizing procedure and was calculated on 3 underwater strokes. From this a mean swimming velocity (V_{swim}, $m \cdot s^{-1}$) during the underwater stroke was obtained. Stroke length (SL) and stroke rate (SR) were obtained during swimming between the 20th and the 28th m of the 50-m freestyle.

Statistical Analyses

Mean and standard deviation (mean ± *SD*) were calculated for all the parameters. To assess time-of-day variations, repeated measures with 1-way ANOVA were conducted for each parameter measured. When ANOVAs revealed significant F-ratios, Student's t-tests and post hoc analyses with Bonferroni corrections were used to identify pairwise differences. For all the statistical analyses, the level of significance was set at $p \leq 0.05$.

Assuming normal distribution for X-Y pairs, Student's t-test provides the highest statistical power. A post hoc power analysis showed that for a t value lower than 2.23, with 60% power, 11 subjects were not sufficient to detect a statistical significance. Because of the limited sample size ($N = 11$), p values ≤ 0.05 were ruled out.

RESULTS

Under pre-exercise conditions, significant diurnal variations in tympanic temperature were detected ($p < 0.01$ between 8 AM and 1 PM, and $p < 0.001$ between 8 AM and 6 PM; Figure 3). The calculated maximal power, optimal pedaling rate, and work output during cycling tests at 8 AM, 1 PM and 6 PM are shown in Table 1. Maximal power was higher at 1 PM and 6 PM than at 8 AM. Interestingly, there was no significant difference between 1 PM and 6 PM. The percentage of variation between 8 AM and 6 PM reached about 7% for maximal power. Such gains in power were totally explained by force improvement at all ve-

Table 1. Cycling parameters at different times of day.

	Vopt (rpm) 8 AM†	Vopt (rpm) 1 PM	Vopt (rpm) 6 PM	Pmax (W) 8 AM	Pmax (W) 1 PM	Pmax (W) 6 PM	Work (30 g·kg^{-1}) (J) 8 AM	Work (30 g·kg^{-1}) (J) 1 PM	Work (30 g·kg^{-1}) (J) 6 PM	Work (60 g·kg^{-1}) (J) 8 AM	Work (60 g·kg^{-1}) (J) 1 PM	Work (60 g·kg^{-1}) (J) 6 PM
ROH‡	120	120	121	886	975	885	13,141	13,154	13,930	16,250	16,165	16,024
REY	139	140	143	1,426	1,404	1,549	15,109	16,608	16,357	19,986	19,218	21,007
LAP	135	130	131	972	1,048	1,103	14,599	15,579	14,888	17,301	16,248	18,254
THO	122	120	121	965	1,057	1,105	13,713	14,646	14,967	16,372	17,502	17,057
MIC	103	107	107	591	586	620	9,409	10,868	10,683	12,653	12,799	13,198
LEY	99	105	102	539	609	613	10,058	10,707	10,562	12,374	13,185	13,099
GRA	130	135	136	882	945	998	13,920	14,927	15,093	16,599	16,408	16,607
BES	107	108	111	483	530	474	9,497	10,446	9,571	10,883	11,811	11,263
DEV	109	100	108	458	475	502	9,949	10,220	10,538	11,409	11,836	11,996
MON	89	114	91	425	524	449	—	10,555	10,818	11,145	11,454	12,264
PAS	101	96	100	507	506	528	10,283	10,206	9,899	11,799	11,810	11,953
Mean	114	116	115	739	787**	802$$	11,968	12,538**	12,482$$	14,252	14,403	14,792$$$
SD	16	14	16	313	310	354	2,315	2,482	2,540	3,120	2,759	3,173

† Differences between 8 AM and 1 PM: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Differences between 8 AM and 6 PM: $ $p < 0.05$, $$ $p < 0.01$, $$$ $p < 0.001$.
‡ See text for abbreviations.

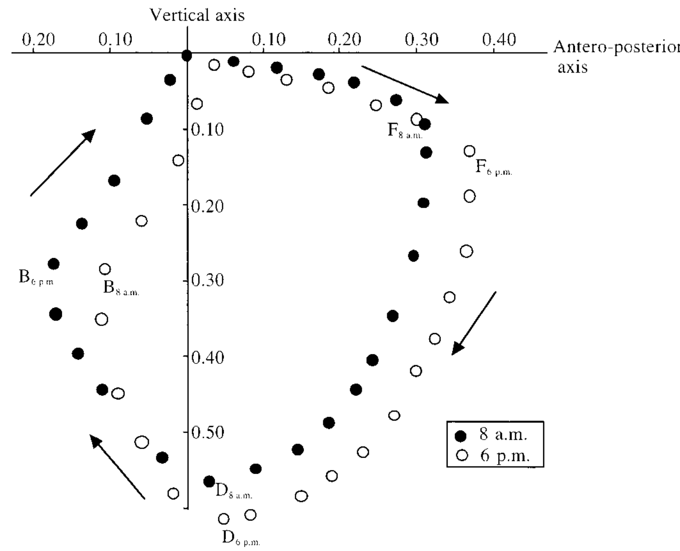

FIGURE 2. Underwater stroke of the hand at two different times of day (8 AM and 6 PM).

locities (Figure 1), and there was no change in optimal velocity (Figure 1 and Table 1). A similar diurnal effect was observed for energy expenditure (work, in joules) at moderate (30 g·kg^{-1}) and high (60 g·kg^{-1}) loads (Table 1). A 5% increase in moderate load and a 3.5% increase in high load were observed between morning and evening ($p < 0.01$).

Diurnal variations between 8 AM and 6 PM ($p < 0.001$) and between 1 PM and 6 PM ($p < 0.001$) were found in 50-m swimming velocity (V_{swim}) (Table 2). Mean amplitude variations reached 4% between morning and evening. Stroke length (in m) decreased between morning and evening ($p < 0.05$), unlike stroke rate (in strokes per minute), which significantly increased between morning and evening ($p < 0.01$).

Technical ability as presently described by antero-posterior and vertical underwater trajectories was strongly modified between morning and evening (Figure 2). Between morning and evening, swimmers increased the first forward movement of the hand by +16% and the maximal depth (D in Figure 2) by 6% (Table 2). However, the backward movement of the hand (point B in Figure 2) did not change.

DISCUSSION

Existence of Diurnal Temperature Variations

Although diurnal changes in performances were not pronounced (4% increase in swim velocity between 6 PM and 8 AM), standard diurnal variations were noted for tympanic temperature. Recent studies (5, 18) have shown that 8 AM, 1 PM, and 6 PM are appropriate times of day for studying diurnal variations. For instance, temperature begins to rise before wakefulness, then increases progressively and reaches the acrophase (peak value) at 6 PM (2). Usually, a variation of about 0.4° C is observed between morning and evening (13, 27, 29). In the present study, similar observations were obtained: auricular temperature was 36.6 ± 0.3° C at 8 AM and reached 37.0 ± 0.2° C at 6 PM ($p < 0.05$). Although body temperature is an important factor having an impact on muscle performance (13, 29), we observed no association between

Table 2. 50-m freestyle swimming analysis at different times of day.†

	V_{swim} 8 AM	V_{swim} 4 PM	V_{swim} 6 PM	SL 8 AM	SL 1 PM	SL 6 PM	SR 8 AM	SR 1 PM	SR 6 PM	F 8 AM
ROH‡	1.84	1.85	1.92	2.22	2.27	2.13	49.83	48	53.12	0.37
REY	1.72	1.75	1.76	2.38	2.44	2.17	42.08	41.69	45.1	0.38
LAP	1.71	1.65	1.75	2.44	2.38	2.28	41.78	40.9	44.5	0.35
THO	1.65	1.69	1.74	2.27	2.38	2.17	42.97	42.28	46.7	0.34
MIC	1.62	1.68	1.71	2.33	2.27	2.22	40.97	43.28	44.6	0.26
LEY	1.64	1.65	1.7	2.5	2.44	2.38	38.73	39.21	40.82	0.27
GRA	1.59	1.62	1.63	1.92	1.96	1.85	49.35	49.4	52.31	0.33
BES	1.52	1.53	1.55	1.72	1.75	1.75	52.44	51.98	52.05	0.24
DEV	1.47	1.51	1.54	2.22	2.13	2.12	39.42	42.06	43.39	0.28
MON	1.42	1.42	1.46	2.13	2.17	2.12	40.22	38.96	41.29	0.27
PAS	1.31	1.32	1.39	1.82	1.96	1.91	43.34	40.2	42.42	0.23
Mean§	1.59	1.61	1.65¶¶¶ ‖‖‖	2.18	2.20	2.10¶¶‖	43.74	43.45	46.03¶¶¶‖‖	0.30
SD	0.15	0.15	0.15	0.26	0.23	0.10	4.64	4.36	4.49	0.05

† Swimming velocity (V_{swim}) in m·s^{-1}; stroke length (SL) in meters (m), stroke rate (SR) in stroke per minute; the most forward coordinate of the hand (F); the maximal depth (D); the backward movement of the hand (B); and the depth at the F coordinate (D_F) were in meters (m).

‡ See text for abbreviations.

§ Differences between 8 AM and 1 PM: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Differences between 8 AM and 6 PM: ‖ $p < 0.05$, ‖‖ $p < 0.01$, ‖‖‖ $p < 0.001$. Differences between 1 PM and 6 PM; ¶ $p < 0.05$, ¶¶ $p < 0.01$, ¶¶¶ $p < 0.001$.

changes in temperature and changes in any parameter studied. However, like others, we found that cycling and swimming performances presented a trough in the morning and a peak in the afternoon, so they vary in accordance with the diurnal variation in body temperature. Experiments in animals have concluded that a pacemaker common to body temperature and locomotor activity is located in the suprachiasmatic nuclei (26).

Diurnal Variations in Maximal Power

A 7% gain in maximal power between morning and evening was observed in the all-out cycling test. Because diurnal changes were very small, great attention was paid to the accuracy of both cycle power measurements and swimming analysis (2). Estimated error values in both measurements were less than 2% whereas the diurnal variations observed exceeded 6%. Moreover, it is worth noting that both experimental methods have already been used in other studies to determine the same type of parameters (7, 14, 32). Similar results were found by Bernard et al. (5), who observed an increase of 5–7% between 9 AM and 6 PM. A higher rate of adenosine tri-phosphate (ATP) turnover could partially explain such an increase in maximal power. It is well known that maximal power output is supported by energy deriving mainly from phosphocreatine and anaerobic glycogenolysis (16). Moreover, a 6-second sprint on a cycle ergometer resulted in a fivefold increase in plasma epinephrine concentrations and a twofold increase in plasma norepinephrine (6, 16, 31). The sympatho-adrenal activity, and thus the plasma epinephrine level (22), demonstrated diurnal rhythms, probably subsumed by a circadian oscillator (26). Because peak epinephrine values were obtained in the early evening, this could explain the better performance noted at that moment in a short-term, high-intensity exercise.

More than diurnal changes in maximal power, the 3–5% increase in energy output at 6 PM supports the hypothesis of a higher sustained rate of glycolysis resulting in lactate formation. Unfortunately, we are not aware of studies using muscle biopsies to measure morning vs. evening highest anaerobic ATP turnover rates.

Diurnal influences in cycling were manifested regardless of the speed of movement. This was illustrated by an increase in maximal power at 6 PM with no concomitant change in the corresponding optimal pedaling rate (Vopt). Accordingly, Gauthier et al. (17) found that elbow flexion torque during concentric movements presented circadian rhythms regardless of the concentric angular velocity. On the other hand, Deschenes et al. (13) suggested that biorhythmic variations in concentric muscle actions of the lower body are speed-specific based on diurnal effects being detected only at the velocity of 3.14 rad·s^{-1}. Recently, Martin et al. (24) failed to demonstrate any diurnal changes in neural activation during maximal isometric muscle contractions, although the generated force was increased at 6 PM. Therefore, this is additional support for the metabolic flux being an obvious candidate to explain diurnal variations in all-out force or power, possibly accompanied by changes in Ca^{++} movements across the sarcoplasmic reticulum.

Diurnal Variations in Technical Ability

Because we are not aware of any experimental evidence of diurnal variations in technical ability, the present study attempted to provide insights in this area. Technical ability is strongly related to high-intensity performances (9, 14, 23). In most studies (8, 11, 12), stroke length has been shown to be the best single independent predictor of swimming performance. Stroke length reaches values similar to those obtained here at 6 PM. Interestingly, the morning values we obtained were somewhat higher ($p < 0.05$). Similar observations were made for stroke rates (SR) where evening values were similar to those obtained in the literature, whereas morning values were clearly lower (Figure 4). Both stroke length and stroke rate results indicated a morning underwater pattern different than that usually observed in afternoon or evening. A detailed analysis of diurnal changes in the swimming technique is also provided in the present study.

Changes were observed for both the most forward movement of the hand (+16%) and the maximal depth (+6%) between 8 AM and 6 PM. Therefore, we suggest that specific adaptations in the swimming technique occur

Table 2. Extended.

F 1 PM	F 6 PM	D 8 AM	D 1 PM	D 6 PM	B 8 AM	B 1 PM	B 6 PM	D_F 8 AM	D_F 1 PM	D_F 6 PM
0.40	0.38	−0.64	−0.65	−0.65	0.42	0.44	0.41	−0.15	−0.14	−0.20
0.41	0.38	−0.65	−0.66	−0.66	0.45	0.46	0.49	−0.17	−0.18	−0.22
0.37	0.37	−0.62	−0.62	−0.65	0.44	0.46	0.48	−0.12	−0.15	−0.17
0.37	0.37	−0.61	−0.63	−0.65	0.48	0.49	0.47	−0.09	−0.08	−0.11
0.29	0.36	−0.56	−0.58	−0.60	0.49	0.47	0.49	−0.05	−0.07	−0.07
0.33	0.38	−0.56	−0.58	−0.60	0.47	0.48	0.47	−0.07	−0.09	−0.09
0.35	0.34	−0.60	−0.60	−0.62	0.47	0.48	0.49	−0.11	−0.12	−0.14
0.28	0.32	−0.50	−0.51	−0.53	0.45	0.46	0.46	−0.05	−0.07	−0.10
0.35	0.38	−0.54	−0.58	−0.60	0.48	0.48	0.48	−0.04	−0.08	−0.09
0.27	0.34	−0.52	−0.52	−0.56	0.44	0.45	0.45	−0.02	−0.07	−0.08
0.27	0.35	−0.52	−0.53	−0.57	0.48	0.49	0.48	−0.07	−0.11	−0.12
0.34***	0.36‖‖‖	−0.57	−0.59**	−0.61¶¶¶‖‖‖	0.46	0.47*	0.47	−0.09	−0.11**	−0.13¶¶¶‖‖‖
0.05	0.02	0.05	0.05	0.04	0.02	0.02	0.02	0.04	0.05	0.04

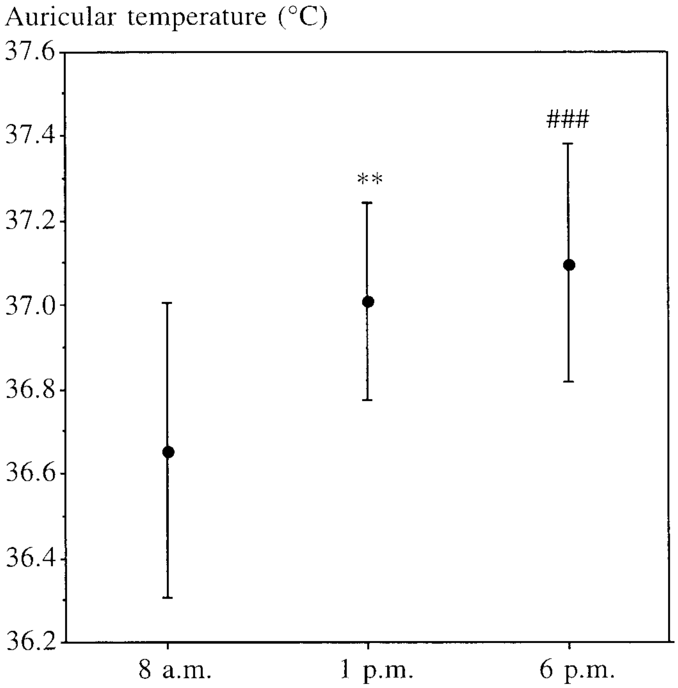

FIGURE 3. Mean auricular temperature at 8 AM, 1 PM, and 6 PM. **Significant difference ($p < 0.01$) between 1 PM and 8 AM. ###Significant difference ($p < 0.01$) between 6 PM and 8 AM.

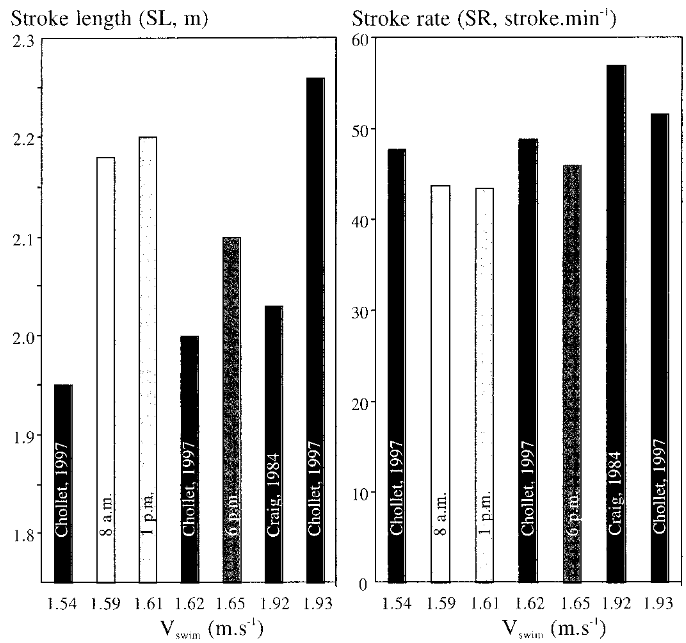

FIGURE 4. Mean values of stroke length (SL) and stroke rate (SR) obtained in this and previous studies.

throughout the day and that these adaptations possibly improve swimming velocities (10). Indeed, a forward movement with little depth in the morning might indicate a long and inefficient glide phase where the hand remains near the surface (Figure 1) (23). On the contrary, a higher forward movement in the evening with the hand having already dived might indicate a more active glide phase. Vertical and insweep movements might participate in propulsion by creating lift forces (4, 34). In the present study, the evening pattern of the hand with a 16% increase in forward movement possibly indicates efficient propulsion.

The next phase, named the pull phase and defined by an essentially vertical movement of the hand to the maximal depth, participates mostly in swimming propulsion in world-class swimmers (14). The 6% increase in the depth point throughout the day provides a substantial enhancement in the underwater pattern, probably partially improving swimming propulsion.

The present results support and extend similar observations concerning better performance conditions in the early evening. Body temperature increases throughout the day, but usually no causal relation is found between temperature and performance. Nevertheless, significant improvements were recorded both in maximal power and in technical ability between morning and afternoon. These improvements likely explain the respective higher swimming velocity in the afternoon.

PRACTICAL APPLICATIONS

Swimming competitions are characterized by morning and evening racing. Because diurnal rhythms naturally facilitate evening performance, some swimmers may encounter difficulties in swimming fast during morning heats, so they may fail to qualify for evening finals. In view of our results, both power and technical capacity depend on diurnal rhythms. Swimmers who need to reach high velocity in the morning must "swamp" their diurnal influences during the previous days. To this end, power training sessions performed in the morning can be helpful in addition to technical exercise. On the other hand, warm-up before morning races should be conducted with particular attention. Indeed, warming up in the morning might substantially improve muscular performance.

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