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Effect of water temperature on performance, lactate production and heart rate at swimming of maximal and submaximal intensity

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The effect of water temperature on performance effort, monitored heart rate and lactate production during freestyle swimming at maximal and submaximal speed has been studied. Fifteen male sprint swimmers performing 100 m swimming and fifteen comparable endurance competitors performing 30 min swimming at submaximal speed served as subjects. Water temperature in separate events was 20, 26 and 32°C. At maximal performance there was a direct relationship between any two of the following parameters: water temperature, average swimming speed, heart rate during the competition and plasma lactate concentration after the event. Thus, the best effort (speed 1.704 m/s), the highest peak heart rate (185 beats/min) and the highest lactate level (19.8 mmol/l) were observed at 32°C (all mean values). In contrast, these values were markedly lower at 20°C. At the submaximal effort, water temperature was related to peak heart rate only. The highest peak heart rate (144 beats/min) was again obtained at 32°C, while the lactate concentration (4.2-5.2 mmol/l) was independent of temperature. Water temperature appears to have a direct effect on performance effort, heart rate and lactate production during swimming at maximal intensity, whereas this effect seems to fade at submaximal efforts.

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The metabolic and functional responses to exercise are influenced by its intensity and duration. An important factor determining the rate of these responses is generally considered to be the environmental conditions. Since thermal regulation of the human body depends on the maintenance of a balance between metabolic heat production and heat loss, the thermal nature of one's environmental medium during exercise is of primary importance.[1] Activities in water appear to be associated with a much more severe thermal load on man compared to activities in air of the same temperature.[2 3] This is due to the fact that water has higher thermal conductivity and thermal capacity than air. In effect, man's thermoregulatory mechanisms are often incapable of maintaining a constant internal body temperature during prolonged swimming, especially when performing in cold water.[4 5]

Although certain aspects of energy production and hormonal, circulatory and respiratory responses to exposure to cold and warm water have been studied, few reports are available on the relationships among water temperature, work rates, telemetered heart rates (HRs) and blood lactate levels during swimming competitions.[2 4 6 7] We decided to further investigate such relationships and, in addition, to compare changes in the above parameters during long-distance swimming at submaximal intensity to those observed during sprint swimming.

TABLE I.—*Characteristics of the subjects.*

	Group A (Sprint swimmers)	Group B (Endurance swimmers)
Age (y)	16.4±0.9	16.2±0.9
Height (m)	1.78±0.03	1.75±0.06
Mass (kg)	70.9±7.2	69.2±5.3
% body fat	16.0±2.3	14.5±2.4
Body surface area (m^2)	1.87±0.09	1.83±0.10
Training age (y)	7.5±2.2	6.9±2.9
Weekly training (km)*	36.5±5.1	41.8±5.9
Weekly dry training (h)*	10.9±1.0	6.0±1.0
100 m freestyle record (s)	57.5±2.4	—
1500 m freestyle record (min)	—	17.5±1.2

*During the last month before the study.

Materials and methods

Fifteen male sprint swimmers (group A) and a comparable group (B) of 15 male endurance swimmers, all of age-group national-team level, participated in the study. Pertinent anthropometric and training data of the subjects appear in Table I. Body composition information was obtained according to the method of Wilmore and Behnke.[8]

All tests were conducted toward the end of the swimming season in a 25 m indoor swimming pool, in which water temperature was accurately regulated. The tests consisted of 100 m freestyle swimming at maximal speed for all subjects of group A and freestyle swimming for 30 min at a submaximal intensity corresponding to the anaerobic threshold for group B. The latter was achieved by asking the athletes to swim at an average speed calculated according to the equation of Hollmann and Liesen:[9]

$$V_4 = 1.367 \times V_{max} - 0.509 \quad \text{(Equation 1)}$$

where V_4 is the speed at the anaerobic threshold and V_{max} was the highest recorded speed of freestyle swimming for 30 min at 26°C for each swimmer of group B (mean 1.298 m/s). At intervals of 5 days and at about the same time of the day (early afternoon) each group performed a single effort in water of 20, 26 or 32°C. Air temperature was 20-21°C.

Heart rates were monitored at 15 s and 5 min intervals for sprint and endurance swimmers respectively by means of Polar Vantage XL™ telemetric HR monitors. Additionally, HRs were obtained 1 min before the start and 1,5 min after the end of each effort. Blood samples were drawn once before the events and 6 min after the end of each competition from an antecubital vein into test tubes containing KF-EDTA. Lactate was assayed enzymatically through a reagent kit from Boehringer-Mannheim (catalog number 149 993).

All values are expressed as mean ± standard deviation. Comparisons were performed by using Student's "t" test. The level of statistical significance was set at $p=0.05$.

Results

The patterns of the resting, anticipatory (immediately preceding the start of the competition), maximal and submaximal exercise and recovery mean HRs at three different water temperatures (20, 26 and 32°C) are shown in Figures 1 and 2. In the 100 m freestyle swimming the mean values of resting HR were similar at the three temperatures, as were also the anticipatory HRs.

However, at each temperature the anticipatory HR was significantly higher than the resting HR (by 16, 14 and 14% respectively). The HRs increased markedly during the initial stages of each swimming event and climbed progressively toward the maximum as the race proceeded. Compared to swimming in 26°C-water, the magnitude of HR responses was significantly higher during swimming at 32°C and significantly lower at 20°C. Finally, the recovery HRs were significantly different at the three water temperatures. The lowest mean HR at 1.5 min of the recovery period was recorded following swimming in the coldest water, while the competition in the warmest water led to the highest recovery HR.

A more complex pattern was obtained with group B (Fig. 2). The anticipatory HRs of these swimmers were not significantly different from the corresponding resting values. During swimming at submaximal speed in 26°C and 32°C water, after a rapid initial (up to 10 min) rise, HRs remained fairly constant through the rest of the effort. Although the HRs during exercise were significantly higher at 32°C than at 26°C, the mean HRs recorded 1.5 min after finish were equal. At 20°C the HRs continued to rise up to 20 min after the start and exceeded the respective values in 26°C water. However, the HRs throughout the competition at 20°C remained significantly lower than the corresponding values at 32°C. Similarly, the recovery HR following swimming in 20°C water was significantly lower than the corresponding HR at 26 and 32°C. It should be mentioned that, although the resting mean HRs were similar between sprint endurance swimmers, the anticipatory, maximal and recovery HRs were significantly higher in group A than in group B, with the exception of the recovery HR in 20°C water.

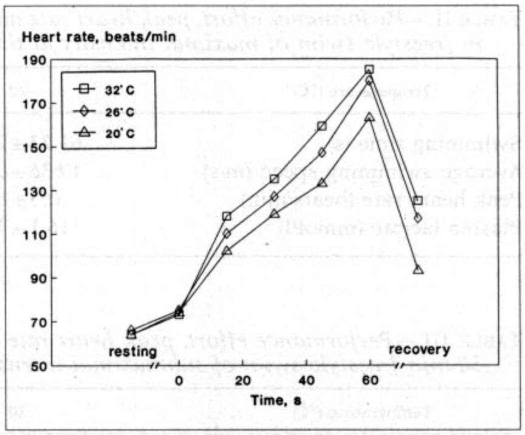

Fig. 1.—Resting, anticipatory, exercise and recovery mean heart rates of group A in a 100 m freestyle swim of maximal intensity at varying water temperatures. *Resting*, 1 min before start; *recovery*, 1.5 min after finish.

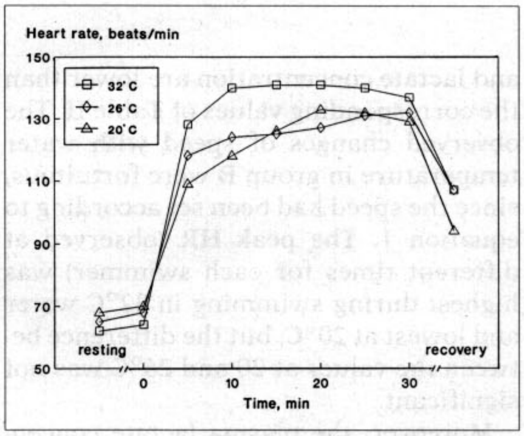

Fig. 2.—Resting, anticipatory, exercise and recovery mean heart rates of group B in a 30 min freestyle swim of submaximal intensity at varying water temperatures. *Resting*, 1 min before start; *recovery*, 1.5 min after finish.

Table II presents the average swimming speed, peak HR (coinciding with the final HR) and plasma lactate concentration at the maximal effort (group A). The lactate concentration at rest was 1.9±0.5 mmol/l. The observed changes in speed, maximal HR and lactate concentration are directly related to water temperature, with all differences being significant except the one between the lactate levels at 26 and 32°C.

Analogous data for the submaximal effort (group B) are shown in Table III.

All values of swimming speed, peak HR

TABLE II.—*Performance effort, peak heart rate and plasma lactate concentration of group A in a 100 m freestyle swim of maximal intensity at three water temperatures.*

Temperature (°C)	20	26	32
Swimming time (s)	61.23±2.48	59.28±1.13	58.74±2.05
Average swimming speed (m/s)	1.636±0.066	1.689±0.057	1.704±0.057
Peak heart rate (beats/min)	163±6	180±3	185±4
Plasma lactate (mmol/l)	16.1±4.2	19.1±5.3	19.8±2.9

TABLE III.—*Performance effort, peak heart rate and plasma lactate concentration of group B in a 30 min freestyle swim of submaximal intensity at three water temperatures.*

Temperature (°C)	20	26	32
Distance (m)	2165±126	2274±112	2276±139
Average swimming speed (m/s)	1.203±0.070	1.263±0.062	1.268±0.077
Peak heart rate (beats/min)	134±4	136±7	144±4
Plasma lactate (mmol/l)	4.6±2.4	5.2±2.1	4.2±2.3

and lactate concentration are lower than the corresponding values of Table II. The observed changes of speed with water temperature in group B were fortuitous, since the speed had been set according to equation 1. The peak HR (observed at different times for each swimmer) was highest during swimming in 32°C water and lowest at 20°C, but the difference between the values at 20 and 26°C was not significant.

Moreover, the plasma lactate concentration rose significantly from 1.4±0.6 mmol/l at rest to mean values ranging from 4.2 (at 32°C) to 5.2 mmol/l (at 26°C). The final values at the three temperatures do not differ from each other significantly. It is noteworthy that the resting plasma lactate concentrations of groups A and B are significantly different.

Discussion

The physical characteristics and the training regimen of both groups (Table I) are in agreement with previously reported data for highly trained swimmers.[10] All swimmers were at the peak of conditioning since they were studied toward the end of the swimming season. The biggest difference between the two groups was observed in the lactate concentration of plasma taken at a time sufficient for equilibration of blood lactate with the intramuscular lactate at the end of each competition. The data clearly distinguish between an intensely anaerobic effort and an effort slightly above what is considered to mark the anaerobic threshold (4 mmol/l [11] [12]). Notably there is a significant difference in the resting lactate values of the two groups, probably reflecting their different muscle fibre composition and training schedules.[5] [12]

Both sprint and endurance swimmers exhibited resting HR considerably lower than reported values for untrained healthy males of the same age.[13]

In sprint swimmers the pre-immersion HR was significantly higher than the resting value because of the anticipatory response to exercise. This response is believed to result from an increase in sympathetic outflow and a diminution of vagal tone due to involvement of the motor cortex preparing the organism for a recognised work task.[14] [15] Contrary to group A, group B did not exhibit anticipatory HR significantly different from the resting values. A finding analogous to the higher anticipatory HR of sprint compared to endurance swimmers has been reported for trained runners.[14]

Monitoring of the HR has been used successfully during competitive swimming events.[4, 6] Our results indicate that the pattern of HR response during maximal and submaximal freestyle swimming is similar to that previously reported for running.[16] However, the magnitude of the response appears less pronounced in swimming. Several investigators have shown that maximal HRs during running are significantly higher than those measured during swimming at the same level of oxygen uptake.[6, 10] In attempting to explain these dissimilarities several factors inherent in each activity have to be considered. These include the medium in which each activity is performed, the position of the body during exercise and the active muscle mass involved in each form of competition.[6]

Our results on the maximal effort indicate a direct relationship between temperature and any of the parameters measured, i.e. average speed of swimming, monitored HR responses throughout the competition and plasma lactate concentration after each event. The observed increase of speed with water temperature can be attributed to an increase of maximal metabolic power (as suggested by the increased blood lactate concentration) and/or to an improved swimming economy. These effects may be due to changes in muscle temperature affecting biochemical and functional processes of the working muscles, as well as to different hormonal, circulatory and respiratory responses.[1, 4, 17, 18] A number of investigators have indeed demonstrated that decreased body temperature during swimming in cold water may elicit catecholamine secretion, enhance muscular glycogenolysis, augment urinary excretion of Na^+, K^+, Ca^{2+} and Mg^{2+} and increase oxygen requirement.[4, 7, 19, 20] The opposite responses were demonstrated during swimming in warm water.[4, 7, 21]

Heart rate during maximal swimming was always lowest in the coldest water (20°C) and highest in the warmest water (32°C). This was also the case for the peak HR, which was attained at the end of each competition. These findings are similar to the ones reported by other investigators.[2, 4, 6, 21] A decline in work capability concurrent with lower HR in cold water has also been observed.[4] The effect on HR has been attributed to peripheral vasoconstriction caused by colder water, which diverts blood from the skin to the working muscles, thereby reducing the cardiovascular load during exercise.[22, 23] Swimming in warm water, on the other hand, causes an increase in HR because a greater part of cardiac output must be directed to the skin.[21]

It is interesting to note that the lowest HR during the early stages of recovery (Figs. 1, 2) was recorded following maximal or submaximal swimming in the coldest water. On the contrary, swimming in the warmest water was followed by the highest recovery HRs. These observations are in agreement with other reports.[2]

The parallel increases in swimming speed, heart rate and blood lactate concentration observed with increased water temperature are in agreement with those reported by others.[12, 24] Having worked with female or male swimmers at apparently the standard swimming-pool temperature, these groups showed direct relationships between any two of the following parameters: swimming speed, final HR and final blood lactate concentration.

Based on our findings, we suggest that water temperature constitutes a primary factor determining the work rate of sprint swimmers. However, the augmentation of performance effort in the warmest water is accompanied by greater metabolic and cardiovascular loads.

The effects of water temperature were less profound in the case of long-distance swimming at submaximal intensity. There the only significant differences were observed between the peak HRs at 32 and 26 or 20°C. The finding of the highest peak HR in the warmest water is in agreement with previous reports.[2 4 25] Our results indicate that the effects of water temperature on workload and cardiovascular responses during long-distance swimming at submaximal effort are less pronounced than those observed during short-distance swimming at maximal speed.

It has been our intention to measure rectal and muscle temperatures in relation to the exercise performed. However, it was impossible to obtain consent from most of our subjects and from their guardians. Therefore, in assessing these parameters we had to rely on the available literature, which shows an increase in core temperature after either maximal or submaximal swimming at water temperatures of 26°C or higher.[2 4 7] Data in reference to lower temperatures are contradictory and difficult to compare, since body composition and intensity of swimming are not always given. Costill *et al.*[2] reported on an increase in core temperature at 17,4°C, whereas Holmer and Bergh [4] and Galbo *et al.*[7] found decreases at 18 and 21°C respectively. Based on the rather high fat content of our individuals, we would favor an increase of core temperature in all cases. This suggestion is enhanced by the observed progressive increase of HR up to 20 min of swimming at submaximal intensity in 20°C water (Fig. 2), which is probably indicative of a progressive increase of core temperature.[4]

Muscle (vastus lateralis) temperature also increases at maximal efforts in 18°C or warmer water.[4] At submaximal efforts it increases in 26°C or warmer water, whereas it does not change significantly at 21 or 18°C.[4 7] These findings presumably hold true for our experiment as well.

Our data on the relationship between water temperature and lactate levels contradict those of Holmer and Bergh,[4] who found significant increases after submaximal swimming as the water temperature decreased from 34 to 26 to 18°C, but no significant changes after maximal swimming which followed the submaximal effort. No explanation other than the completely different experimental protocols employed is available at the moment.

We conclude that changes of water temperature in swimming at maximal intensity elicit parallel changes in performance effort, monitored HR and lactate production. These effects become less visible at submaximal efforts. Further research might pinpoint possible training benefits from swimming at varying temperatures.

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