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The effect of water temperature on the human body and the swimming effort

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ABSTRACT

Although many research papers have dealt with the influence of environmental temperature on the various Human body functions during exercise in land, a few only informations exist for the equivalent alterations in water temperatures during immersion and swimming.

The present preview research paper is referred on this subject.

During swimming in the normal water temperature 26° ± 1° C (63), the functions of the human body respond regularly and the performance of swimmers tends to be improved. However, during swimming in cold water critical differences appear in human functions, such as bradycardia, angiospasm, hyperventilation and adaptations of thermoregulatory mechanism which influence the swimming performance and the life itself. Especially in very cold water temperature the disturbances of the cardiovascular system may lead in critical arrhythmia or sudden death. The cold water temperature, however, influences the kinetic and energy behavior related to the reduction of swimmers performance because of its possible influence on the neuromuscular function.

In the increased water temperature up to 28° C appears tachycardia, vasodilation and other alternations which aim to better thermoregulation. The swimmers records are possibly equivalent with a tendency to be improved, to the records in normal temperature of championships 26° C and the increased temperature mainly in the speed events (3).

Therefore, there is a differentiation on swimmers performances due to water temperature declination from normal. Also, body functions change during water immersion.

Key Words: *Water, Temperature, Changes, Body, Swimming, Performance*

INTRODUCTION

The immersion of the human body in water causes reactions in bodily functions, which result from the natural and chemical properties of water, and which, gradually or abruptly, are conveyed through the skin into the interior of the organism, thus affecting behavior both at rest and during exercise and competition. Water temperatures, in particular, are a primary factor affecting and altering functions, with a consequent variation in the performance and behavior of the body in water.

Water is a much better heat conductor than air. The coefficient of transport of alternate heat for a body at rest in still water is 230 watts $\cdot m^{-2} \cdot °C^{-1}$ (44), while in still air it is approximately 9 watts $\cdot m^{-2} \cdot °C^{-1}$ (15). One method used for normal human reactions to cold establishes the critical temperature, which is defined as the lowest air or water temperature that does not cause an increase in metabolic rate over a time period of three hours. Peripheral angiospasm and reflexive behavior of the insulating tissue maximize their function before tremor (shivering) sets in and thermogenesis commences (58). The critical temperature of water is many degrees higher (28 °C to 33°C) than the critical temperature of air (21°C to 27°C), reflecting water's greater water conductivity. Thermal neutrality is achieved in water temperatures of 33°C to 34°C, a condition that permits mild swimming activities (35, 41).

Extreme exposure to cold water and survival (temperatures below 20°C) results in an abrupt increase in metabolic rate, because of the stimulation of cold receptors in the skin (33). Such exposure may occur as a result of a boating accident or other human activities on water, of by a fall into frozen water thought broken ice. Of the increase in metabolic rate, 30% is expended in heat loss in the effort to remain afloat with a flotation device. If swimming increases metabolic rate approximately three times more than tremor (shivering), then the rate of ultimately lost heat increases significantly. Hayward et al. (32) suggest that, in temperatures below 20°C, it is absolutely necessary for humans that fall into the water to remain completely still, rather than to attempt to swim, unless they are very close to the shore. Movement in water increases heat loss through the skin, because skin temperature rises due to the activity of arm and leg muscles, and consequently the thermal variation between skin and water increases (32). Through these increases, loss of body heat is precipitated. Very high skin temperatures while at rest in still water are observed on the upper part of the chest, the sides of the thorax, and the groin. This occurs, quite possibly, due to the low amount of subcutaneous fat tissue and muscles that cover these areas, and the proximity of the blood vessels on the surfaces of the above areas to the cold water environment.

Swimming and changes

Bearing in mind that thermal conductivity is much greater in water than in the air, normal reactions during exercise in comparable air and water temperatures are not always the same. In water temperatures of 25°C and below, oxygen consumption (VO_2) Increases in a faster rate than air at temperatures of 25°C, and cardiac frequency is reduced (16, 41). Oxygen consumption (VO_2) increases because the tremor creates thermogenesis and possibly a decrease in mechanical ability during exercise. The cardiac output increases linearly with an increase in peripheral vasoconstriction in cold water. When water temperatures are at 30°C and above, metabolic rate and cardiac frequency are the same in both air and water environments. If the increase of pulses volume is due to the effects of hydrostatic pressure from the increasing peripheral vasoconstriction, then cardiac frequency could be depressed in warm water.

Heat dissipates quickly in cold water, and swimming in sub-maximal temperatures reduces the body's core temperature, even thought the metabolic rate increases (34). The increase in metabolic rate is inversely proportionate to the increase in water temperature. The levels of lactic acid are increased during sub-maximal swimming distances in cold water, while muscle temperatures could alter physical and chemical functions in the muscle's interior during swimming, ultimately resulting in the reduction of mechanical ability in cold water.

The Human Body and External Effects

The temperature of the water environment affects both the performance of swimmers, and their bodily functions. A basic object of this paper is the presentation of changes in the function of various systems of the organism, as well as of muscle output during swimming in various water temperatures.

Changes are observed both in the core (centre) of the body, and on the periphery (surface, skin), resulting in the appearance, depending on the temperature fluctuation, of gradual phenomena of hypothermia or hyperthermia. Since, it has been established that in low water temperatures (21°C), a reduction in rectal temperature below 37°C is observed. Conversely, in high water temperatures, there is a tendency for rectal temperature to rise above 38°C (34, 35).

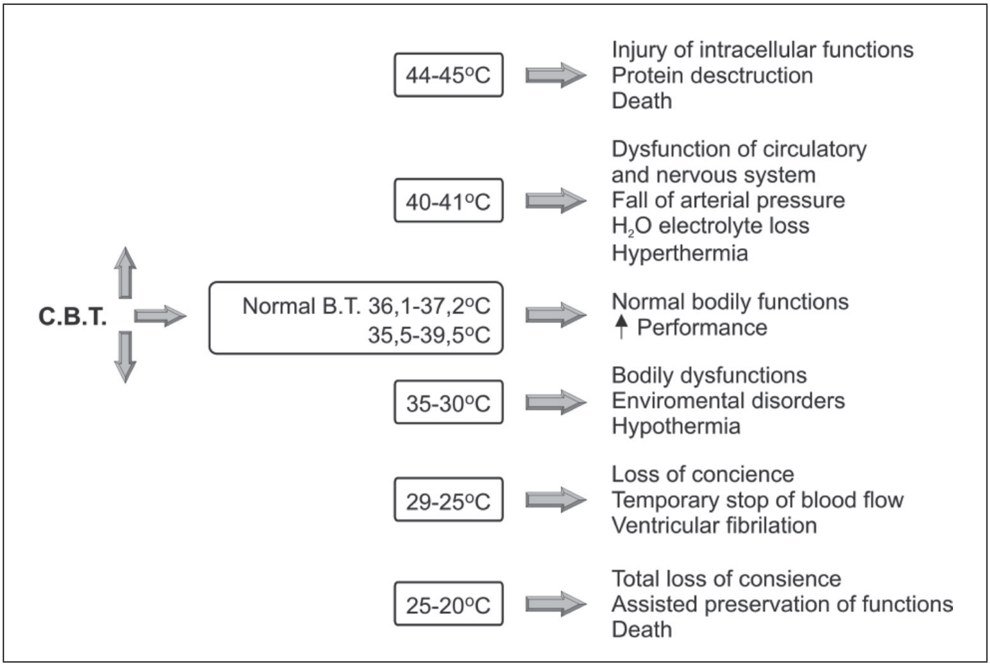
Table I lists the zones of the body's core temperature (CTB) and the general reactions of the organism to its increase or decrease.

The body's regular temperature fluctuates over a 24-hour period from 36,1°C – 37,2°C (43).

The limits of the core temperature, within which no noteworthy changes are observed during the swimming effort, range from 35,5 °C – 39,5 °C (16, 43). In temperature variations above or below these limits, there occur gradual phenomena of malfunction, reduced performance, or even death (22).

When changes occur in water temperature, a reflexive change of vasomotor tone in the skin blood vessels is observed, resulting in the appearance of peripheral and central effects. Hence, skin receptors are stimulated, resulting in vasoconstriction or vasodilatation. Similarly, effects appear in the brain, the heart, the lungs, the intestines, and the muscles (35).

Table 1. *Central Body Temperature. Different temperatures and functions.*



Abbreviations: C.T.B. – Central Body Temperature
Normal B.T. – Normal Body Temperature
Arrow pointing upwards- increased performance

Reactions to cold and hot water

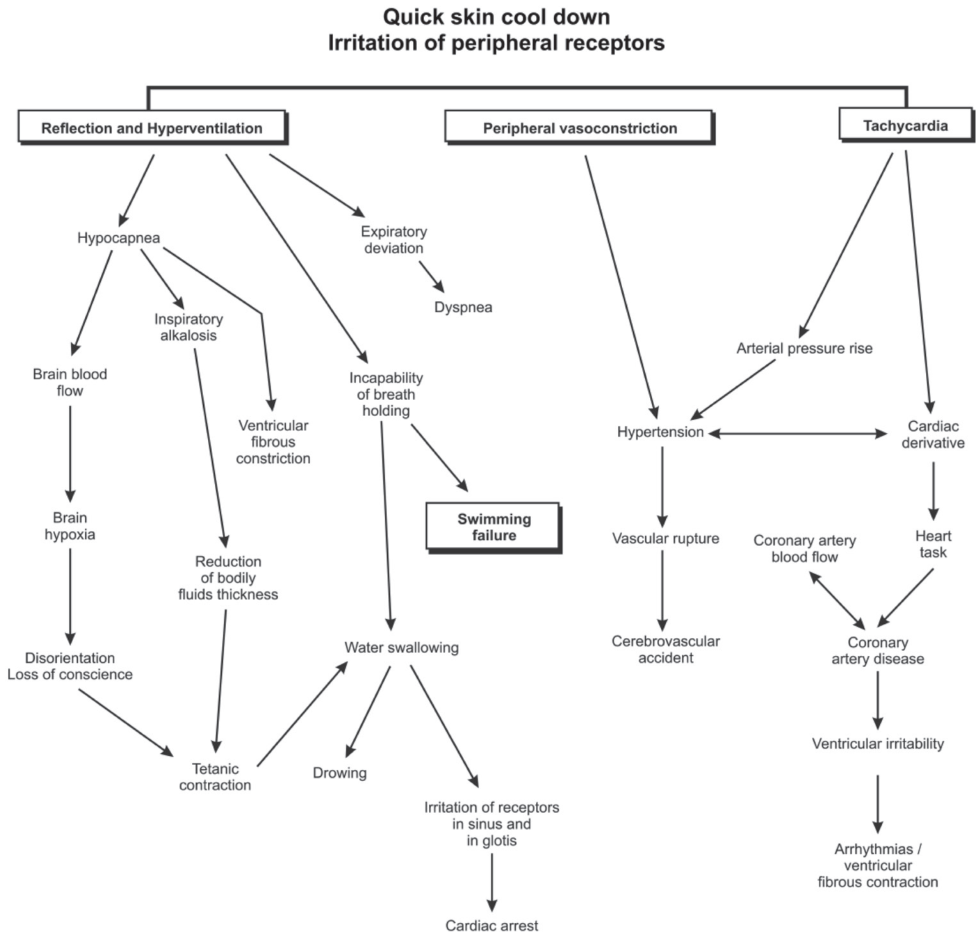
Cold water causes the stimulation of cold receptors, resulting in the appearance of angiospasm. The proportion of fat tissue and the thickness of the skinfold play an important part in the heat-exchange ratio between water and skin (35).

High water temperatures, conversely, cause the stimulation of heat receptors, resulting in pronounced vasodilation and overheating of the body (43).

Table II (60), list in brief the reactions of the organism to cold water and their consequences. The body, though a series of reflexive or sequental reactions (respiratory, skin, and heart function), is led to exhaustion, inability for swimming performance, or even death.

Ultimately, peripheral reflexivity directly affects respiratory and cardiac functions, altering all the function indexes of the lungs, heart, and vessels, resulting in the overall reduction of the organism's response for survival and performance.

Table 2. *Summary of central and peripheral adaptations to cold water.*



From Tipton, M. j. 1989

Changes in the Cardio-respiratory System

Acute changes appear in the cardiovascular system, which affect the performance of muscular function respectively (41, 43).

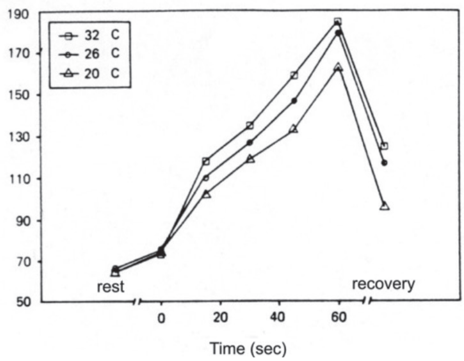
Low water temperatures initially cause reflexive tachycardia (increase of 10-20 b.p.m.), and subsequently bradycardia, an increase in arterial blood pressure, cardiac output and cardiac function, and the emergence of the risk of arrhythmias (35, 60).

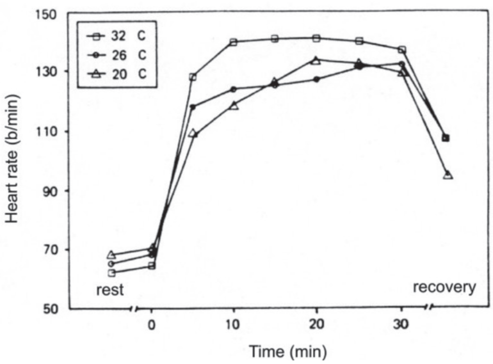
High water temperatures lead to tachycardia, a small change in arterial blood pressure, an increase in blood volume per minute, and a small increase in pulse volume (35).

In graphs 1, 2 (18), we can observe the changes in cardiac frequency during maximal and sub-maximal effort, at water temperatures of 20°C, 26°C, and 32°C, in speed and endurance swimmers (3).

Graph 1: *Alterations of speed swimmers' heart rate of maximal effort in three water temperatures, 20°, 26° and 32°C.*

Graph 2: *Alterations of endurance swimmers' heart rate submaximal effort in three water temperatures 20°, 26° and 32°C.*





From Deligiannis A., 1992

At low water temperatures (18°C), we observe low fluctuation of cardiac frequency during the swimming effort, in high water temperatures (34°C), we observe increased cardiac frequency.

Significant changes occur in the respiratory system. At low water temperatures, we have phenomena of hypoventilation, respiratory alkalosis CO_2 deficiency, and dyspnea, which result in the restriction of CO_2 expiration. At high water temperatures, we observe hyperventilation, restriction of the breadth of the respiration, general discomfort in the respiratory mechanism (22, 23, 42, 48).

Changes in the Hormonal and Muscle Systems

Changes are also caused in the behavior and of secretion of hormones. At low water temperatures, we observe a rise in the secretion of adrenaline, and noradrenaline, as a direct consequence of thermoregulation, an increase of thyroidal hormones, and a decrease of cortisol secretion (25, 37,65).

At high water temperatures, there is also an increase of adrenaline and noradrenaline, a decrease of cortisol, and a decrease o thyroidal hormones: (25).

Also significant are the changes that are observed in the muscles, due to the effect of water temperature and the swimming effort.

At low water temperatures, we note a decrease of enzyme activity, a decrease of blood flow, and a decrease in fluid reaction and in the behavior of electrolytes; as a result, there is a significant drop in performance (34). At high water temperatures, conversely, we note increased blood flow, increased fluid production, weak enzyme activity, and localized hypothermia, resulting in the existence of several differing opinions as to the effect on performance (34).

Changes in esophageal and muscular temperatures are observed in swimmers with differing percentage rates of body fat and skinfold, during running and swimming at three different water temperatures (18°C, 26°C, 34°C), at sub-maximal and maximal effort (34).

Overall, it is noted that muscular temperature is higher than esophageal temperature at the conclusion of sub-maximal and maximal effort. It is also noted that, during running and during swimming at a water temperature of 34°C, at sub-maximal and maximal intensity, there is a tendency for an increase of esophageal and muscular temperatures above 38°C (61).

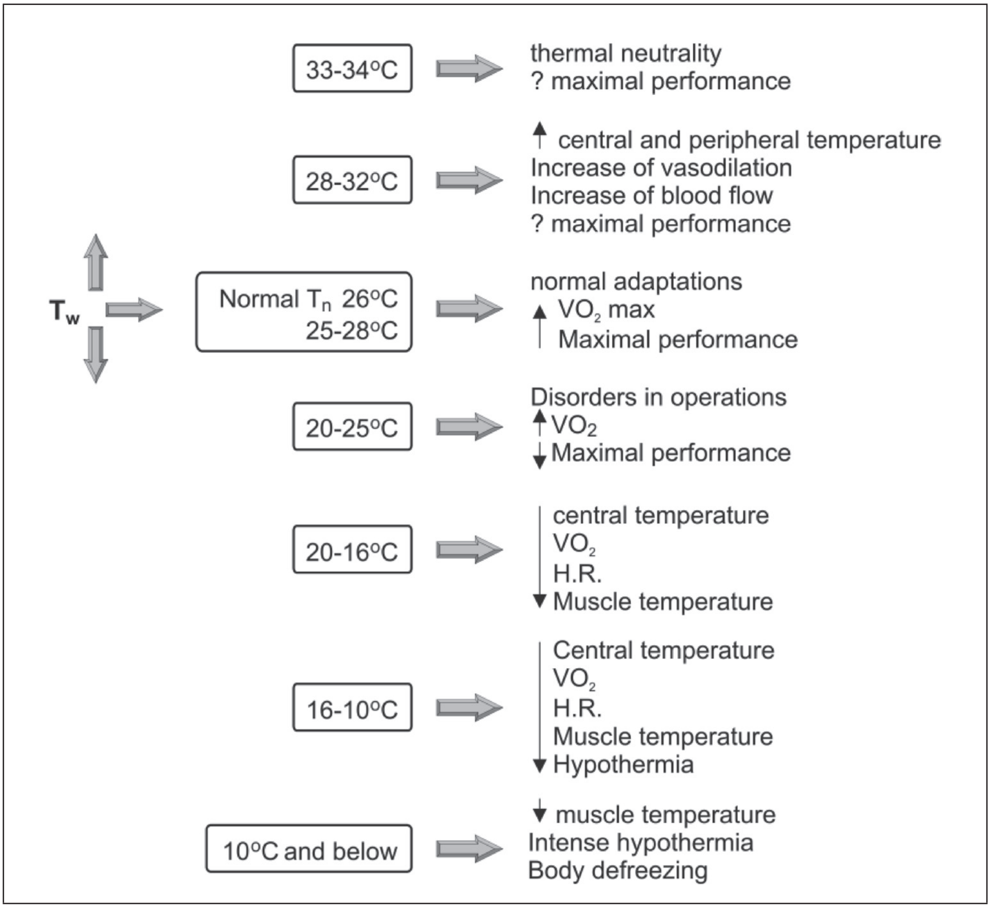
Conversely, during swimming at a water temperature of 18°C, it is noted that esophageal and muscular temperatures tend to decrease, below 37°C (32, 33, 60).

Finally, the lowest values for esophageal and muscular temperatures are observed in the swimmer with the lowest percentage rate of body fat and skinfold (34, 35).

Water Temperatures and Swimming Performance

Table III lists the zones of water temperature and zones of water temperature and the organism's behavior in regards to performance.

Table 3. *Different water temperatures, bodily functions and swimming performance.*



Abbreviations: T_w = water temperature
Normal T_n = normal water temperature
Arrow pointing upwards = increase (central and peripheral temperature, increase of VO_2, increase of maximal performance)
Arrow pointing downwards = decrease of performance, decrease of maximal performance, decrease of central temperature, decrease of VO_2, decrease of heart rate, decrease of muscle temperature)

A water temperature of 26°C, plus °C, is considered the norm for practice and competition, in conjunction with environmental air temperatures and the distance of the swimming contest. At these temperatures, the maximum oxygen consumption peaks, and normal regulatory functions reach their upper limits. Hence, swimming performance is maximized in the water temperature zone of 25°C to 29°C. These temperatures are appropriate both for speed and endurance swimming races. Swimmers in endurance events perform better at temperatures from 25°C to 27°C, while swimmers in speed events perform better at temperatures from 27°C to 29°C (16, 34, 57).

When water temperatures rise between 30°C to 34°C, there is intense vasodilatation, strong blood flow, an increase in the peripheral and core temperatures, and a decrease in performance. These temperatures are appropriate foe exercise activities for infants and children, as well as for the elderly (65, 55).

When temperatures drop between 25°C to 20°C, there is pronounced vasoconstriction, an increase in oxygen consumption, a decrease in peripheral and core temperatures, and a drop in maximum performance. These temperatures are appropriate for endurance swimmers (12, 57, 45).

When water temperatures fall between 20°C to 16°C, there is very pronounced vasoconstriction, a decrease in oxygen consumption, a decrease in peripheral and central temperatures, pronounced phenomena of hypothermia, and a minimization of performance. Marathon swimmers compete at these temperatures, when phenomena of hypothermia are observed (34).

When water temperatures drop below 16°C, there is very pronounced decrease in cardiac frequency and oxygen consumption, a very pronounced drop in core temperature, a gradual decrease in muscle temperatures, an inability to swim, and a gradual cooling of the body (34, 22, 59).

In water temperatures below 12°C, the following occur: rapid drop of core temperature, rapid stop of muscle temperature, pronounced cooling of the body, all the phenomena listed in Table II (59, 32, 33, 67).

CONCLUSIONS

Water temperature immediately affects bodily functions upon entry into the water, throughout immersion and during swimming, gradually provoking changes which affect the condition of the organism, as well as its overall performance. The increase or decrease of the water temperature beyond the normal range may act therapeutically, entertainly, or to enhance the body's physical fitness, but it does not contribute to the improvement of performance.

When the human body is immersed in water, body temperature changes. This change due to and influenced by several factors, such as: water temperature, air temperature, air currents, environmental moisture, the composition and percentage rate of tissues in the body, the percentage rate of fat tissue, and the percentage of immersion of the body in water.

During exercise in water temperatures between 26°C and 28°C, in healthy adult individuals, a low and pleasant body temperature is observed. These temperature are present in most swimming pools and they have a strong effect on the human body, such as: only a few minutes after immersion of the body in water, skin temperature is equalized with water temperature (with a difference of approximately 1°C), since heat conductivity is 25 times greater in water than in air.

In a state of rest-immobility, in water temperatures of 33°C – 34°C, the human body acquires thermal neutrality; this allows for mild swimming activities, with entertaining and therapeutic properties. These high temperatures are appropriate for mild activities for infants and children, the elderly, and fragile or injured individuals.

At water temperatures below 30°C, hypothermia progressively sets in.

In competitive swimming, any increase or decrease of the water temperatures beyond the norm (63), chain reactions and effects between organs, systems, mechanisms and substances are observed, on the surface and inside the body; these result in changes in their functions and/or activities, and strongly affect the outcome of the swimming effort.

At water temperatures ranging from 28°C to 32°C, there is a tendency for performance to improve, primarily in speed events. However, at temperatures higher than that, performance decreases and other goals are pursued. In temperatures much higher than this range, staying in the water becomes impossible and pronounced phenomena of hypothermia occur.

At water temperatures ranging from 25°C to 27°C, there is a tendency for performance to improve, primarily in endurance events. However, at lower temperatures performance drops, and perhaps there is a need to investigate the appropriate temperature for marathon and hyper-marathon swimming.

When water temperatures drop below 25°C to 20°C, malfunctions appear in the organism, the swimming effort and performance is reduced and remaining in the water becomes difficult, with phenomena of hypothermia.

When water temperatures drop below 20°C to 12°C, pronounced malfunctions appear in the organism, the swimming effort and performance is reduced and remaining in the water becomes difficult, with gradual phenomena of hypothermia. Only practiced, fit individuals can swim in these conditions.

When water temperatures drop below 12°C, pronounced and immediate malfunctions appear in the organism, there is complete inability to swim or perform, inability to remain in the water for longer than 1 hour, and pronounced phenomena of hypothermia and cooling of the body.

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