American Red Cross
Scientific Advisory Council

# ARC SAC Scientific Review
# Water Temperature for Aquatic Instruction

**Questions to be addressed:**

Water Temperature

- What is the appropriate safe temperature -range for conducting ARC aquatic programs?
- Are safe temperature ranges different for head-in vs head-out immersion activities?
- What variables exist that affect temperature ranges?
- What associated variables should be considered in modifying the suggested range?

**Introduction/Overview:**

Water temperature is a major factor in participant comfort and overall success of an American Red Cross Aquatic Instruction programs. Water that is too cold can lead to chilling and discomfort and result in limiting the time spent on necessary practice. The ARC currently references the Aquatic Exercise Association (AEA) guidelines for water temperature stating "a comfortable water temperature for swim classes is between 83° to 86°F (28.3° to 30°C)". These guidelines have recently been revised and updated for 2010. The current recommendation given for children swim lessons is 84°F / 28.9°C. The range that is listed as "ideal" for a "Learn to Swim (LTS)" program is from 84-89°F or 28.9- 31.7°C. The range of water temperatures recommendation for infant/ pre-school (ages 4 and under) programming is 90-93°F or 32.2 - 33.9°C.

The AEA guidelines also include a statement that suggests that these guidelines may not be appropriate for every program. For example, it is an accepted fact that "young children are more susceptible to hypothermia than older children" (ARC p.148). Red Cross recommends that if water and air temperatures cannot be maintained within acceptable ranges, the lesson needs to be shortened. These statements show recognition that there is a direct relationship between water temperature and time / duration of the lesson but there is little guidance beyond these reference statements.

In addition to age of the participant and duration of the lesson, temperature ranges may also need to be adjusted based on the type of programming. What this means for American Red Cross LTS programs is what levels are being offered and will participants be able maintain a level of activity that will support thermoregulation. Keeping participants active or active enough to stay warm is not always possible with every level. Limitations might include the size of the practice area, children who do not possess enough skill to keep moving or classes that are so large that participants stand around waiting for a turn. Any of these scenarios may require an adjustment to the water temperature recommendations.

And then there are programs that truly operate outside the norm for LTS programs ("norm" meaning the program structure currently recommended in the Water Safety Instructor Manual). Therefore, it is the purpose of this review to confirm the recommended temperature ranges provided by AEA and USA Swimming, to identify significant variables that affect thermoregulation and to provide more guidance where temperature extremes are the norm or program types and structure vary widely.

**Review Process and Literature Search Performed**

Pubmed search, Google scholar. Pubmed searched for studies using variations of the following concepts: cold water immersion, thermoregulation, thermal balance, immersion hypothermia, temperature regulation, swimming and water temperature. We found 116 articles and rejected 41 of these as not relevant to the question.

Also reviewed was 2010 USA Swimming Rules and Regulations (rule 103.6), American Red Cross Water Safety Instructor Manual, Aquatic Exercise Association (AEA) 2010 Standards and Guidelines Aquatic Fitness Programming, and Review of bibliography of selected manuscripts.

The criteria for considering studies for this review included only human studies (no mechanical models), swimming research with reference to water temperature and intensity of exercise and immersion to at least the middle of the sternum (head-in full immersion preferred but not required).

**Definitions Relevant to the Discussion**

From Bligh J, and Johnson KG. Glossary of terms for thermal physiology. *Journal of Applied Physiology* 1973; 35(6): 941-961

ACCLIMATION: A physiological change, occurring within the lifetime of an organism, which reduces the strain caused by experimentally induced stressful changes in particular climatic factors.

ACCLIMATIZATION: A physiological change, occurring within the lifetime of an organism, which reduces the strain caused by stressful changes in the natural climate.

AREA TOTAL BODY (Aρ): The area of the outer surface of the body assumed smooth. [$m^2$]

BODY HEAT BALANCE: The steady-state relation in which heat production in the body equals heat loss to the environment.

CRITICAL TEMPERATURE, LOWER: The ambient temperature below which the rate of metabolic heat production of a resting thermoregulating animal increases by shivering and or nonshivering thermogenic processes to maintain thermal balance. *CRITICAL WATER TEMPERATURE (Tcw): the lowest water temperature in which a human subject can be immersed to the neck for a period 3 hours without shivering.*

FEVER: A pathological condition in which there is an abnormal rise in core temperature (Tc). The temperature rise in an individual may be considered as fever when it is greater than the mean SD for the species in basal condition.

HABITUATION: Reduction of responses to or perception of repeated stimulation.

HEAT STORAGE, CHANGE IN: The gain or loss of heat associated with change in body temperature or body mass.

HOMEOTHERMY: The pattern of temperature regulation in a TACHYMETABOLIC species in which the cyclic variation in core temperature, either nychthermally or seasonally, is maintained within arbitrarily defined limits (±2°C) despite much larger variations in ambient temperature.

HYPOTHERMIA: The condition of a temperature regulating animal when the core temperature is more than one standard deviation (1 SD) below the mean core temperature of the species in resting conditions in a thermoneutral environment.

MET: an assigned unit of measurement to designate "sitting-resting" metabolic rate of man. 1 met = 58.15 $W \cdot m^{-2}$ = 50 $kcal \cdot h^{-1} \cdot m^{-2}$

It is an empirical unit of measurement to express the metabolic rate of a man whose clothing has an insulative value of 1 CLO when he is sitting at rest, in comfortable indoor surroundings (21°C).

METABOLIC FREE ENERGY PRODUCTION (*M*): The rate of transformation of chemical energy into heat and mechanical work by aerobic and anaerobic metabolic activities within an organism, usually expressed in terms of unit area of the total body surface area.

METABOLIC HEAT PRODUCTION (*H*): Rate of transformation of chemical energy into heat in an organism, usually expressed in terms of unit area of the total body surface.

METABOLIC RATE (MR): see *M*. MR may also be given as the total free energy production in the organism in unit time [W] or as the free energy production per unit mass of tissue in unit time [$W \cdot kg^{-1}$].

METABOLISM: is a general term which relates to chemical and physical changes occurring in living organisms. In thermal physiology METABOLISM invariably relates to the transformation of chemical energy into free energy . . .

TEMPERATURE, AMBIENT (Ta): The average temperature of a gaseous or liquid environment (usually air or water) surrounding a body, as measured outside the thermal and hydrodynamic boundary layers that overlay the body [°C].

TEMPERATURE, CORE (Tc): The mean temperature of the tissues at a depth below that which is affected directly by a changing the temperature gradient through peripheral tissues. Mean core temperature cannot be measured accurately, and is generally represented by a specified core temperature, e.g., that of the rectum (Tre) [°C].

TEMPERATURE, MEAN BODY (Tb): The sum of the products of the heat capacity and temperature of all the tissues of the body divided by the total heat capacity of the organism.

Note: This heat capacity cannot be determined precisely in the living organism. Mean body temperature can be estimated approximately from measures of skin (mean skin temperature; Tsk) and core temperature.

TEMPERATURE REGULATION: The maintenance of the temperature or temperatures of a body within a restricted range under conditions involving variable internal and /or external heat loads.

TEMPERATURE REGULATION, BEHAVIORAL: The regulation of body temperature by complex patterns of responses of the skeletal musculature to heat and cold which modify the rates of heat production and/or heat loss (e.g., by exercise, change in body conformation, and in the thermal insulation of bedding and (in man) of clothing, and by the selection of an environment that reduces thermal stress).

THERMAL COMFORT: Subjective satisfaction with the thermal environment.

THERMAL CONDUCTANCE, TISSUE: The rate of heat transfer per unit area during steady state when temperature difference of 1°C is maintained across the tissue.

Note: this term relates to heat transfer down a temperature gradient from any tissue to its immediate environments, e.g., from a tissue to circulating blood as well as from the body core through peripheral tissues of the body surface.

THERMAL CONDUCTIVITY (k): A property of the material defined by the flow of heat by conduction through unit thickness of the material per unit area and per unit temperature difference maintained at right angles to the direction of heat flow.

THERMAL STRESS: Any change in the thermal relation between an organism and its environment which, if uncompensated by a temperature-regulatory response, would disturb the thermal equilibrium.

THERMOGENISIS, SHIVERING: An increase in the rate of heat production during cold exposure due to increased contractile activity of skeletal muscles not involving voluntary movements and external work.

THERMALNEUTRAL ZONE (TNZ): The range of ambient temperature within which metabolic rate is at a minimum, and within which temperature regulation is achieved by nonevaporative physical process alone [°C]

**<u>Scientific Foundation:</u>**

Much research has been done on immersion hypothermia, survival rates and safety measures. These will not be reiterated in this work.

***Thermoregulation***

Human beings, as all warm blooded animals, maintain core temperatures (Tre or Tc) within a very narrow range. The average core temperature of a human is around 37°C (98.6°F) and body temperature extremes are demonstrated as a fever at 37.7°C (100°F) and when the mean body temperature falls to approximately 35.4°C (95.7°F) (20) just slightly more than 2°C. Therefore, our ability to regulate body temperature is critical for life safety and comfort.

Thermoregulation depends on the dynamic balance between heat gained (or generated) and heat lost to the environment. When a thermal stress is imposed on a human body, it reacts with a combination of metabolic and cardiovascular adjustments to maintain thermal comfort. The basic patterns of cold regulation include heat production by shivering and vasomotor responses which transfer heat down a thermal gradient from core to skin and then from skin to the environment. Vasoconstriction is a cold defense reaction that helps conserve heat by restricting blood flow to the periphery. When peripheral responses have been maximized, humans must either add insulation or rely on their ability to increase metabolism.

General responses to cold stress, whether in air or water, are similar in nature. However, resistance to the flow of heat energy is lower in the water as compared to air and becomes much lower when the skin and/or water are in motion. This makes temperature regulation during immersion more challenging than in air (29, 45, 47, 48).

The most comfortable temperature for a person at rest is referred to as “thermoneutral”. This is the temperature at which unprotected man, at rest, will neither lose nor gain heat. Thermoneutrality in air is around 22.2°C (72°F)(19). An equivalent water temperature would be around 33°C (91.4°F). Cannon and Keatinge (1960) call this the “theoretical critical temperature”, where man “could, in theory achieve thermal stability without an increase in metabolic rate . . .” (p. 338). Craig and Dvorak (1966) suggest that a neutral water temperature, (demonstrated by a mean body temperature that is the same at the beginning of an hour of immersion as at its conclusion) would have to be 34.6°C (94.2). Sagawa et al. (1988) confirm these findings. They reported thermoneutral for their subjects as a water temperature of 34°C.

***Comparing Research***

Research involving human response to cold immersion is plentiful and in general seeks to establish different critical temperatures using a variety protocols. However, because direct measurement of the hypothalamic temperature is not possible, other interactions must be used (6). The selection of measurements and the variety of combinations makes it difficult to compare results. The most common temperature measurements include core temperature (rectal temperature and sometimes esophageal temperatures in adults), esophageal and tympanic temperature (in younger adults and children), skin temperature, mean body temperature, subcutaneous fat thickness, surface area to mass ratio and a variety of metabolic responses including $VO_{2max}$ and metabolic rate.

Comparing research is further complicated because of differences in methodology. Studies differ with the temperature of the water, duration of exposure, depth of immersion (head-out, head-in, chest deep, to the first thoracic vertebrae), body position (vertical, semi recumbent, horizontal) and type of and intensity of exercise (assuming that an exercise protocol is used). It is therefore prudent to proceed with caution when trying to compare results.

The most common water temperatures used to study an unprotected subject at rest during head-out immersion include 15°C (9, 35, 36, 41, 71, 72), 18°C (4, 16, 24, 25, 63), 20°C (8, 9, 23, 38, 42, 43, 71, 72), 25°C (8, 9, 32, 36, 39, 41, 69), 26°C (12, 16, 24, 65), 28°C (12, 39, 42, 43, 62, 71, 72). From these studies, certain general statements can be made. The following are general responses to water immersion in temperatures ranging from 15°C to 33°C:

1) There is a direct relationship between water temperature (Tw) and the length of time a person can be comfortably immersed. (7, 12, 26, 34, 37, 39, 53, 65,75) (*As would be expected, when water temperature decreases, the duration of comfortable immersion also decreases.)*

2) Metabolic rate increases as the temperature of the water decreases (7, 8, 16, 24, 32, 57, 62). *(Shivering is similar to light exercise which increases the metabolic rate).*

3) The range of water temperatures in which man can attain thermal balance can be extended by reducing the total surface area exposed to the water, by exercise (9, 13, 32, 36, 43, 44, 50, 57, 65) and by adding clothing (10, 22, 29, 34, 36, 51, 52,73).

4) Head submersion increases the cooling rate of the body (22, 28, 39, 52, 62, 69).

5) If water temperature and duration of immersion are controlled, there are a number of factors that act in concert to extend or reduce thermal comfort. These include but may not be limited to; surface area to mass ratio(14, 25, 26, 28, 38, 39, 44, 59 61, 63), subcutaneous fat thickness (3, 4, 7, 8, 9, 16, 24, 25, 28, 34, 35, 38, 42, 44, 49, 53, 54, 59, 60, 62, 64, 65, 69) , age (10, 15, 18, 23, 40, 59, 62, 63, 71, 72, 73), gender (28, 37, 39, 40, 42, 43, 55, 59, 63, 71 ), rest v exercise (9, 26, 28, 32, 41, 45, 49, 65), level of fitness (15, 34, 40), and possibly acclimation (55)

6) The type and intensity of exercise in the water affects the cooling rate of the body. (*walking, cycling, rowing, swimming, arm ergometer are examples that appear in these protocols*) (9, 11, 13, 20, 26, 28, 29, 36, 41, 47, 58, 67).

7) The ability of the arms to retain heat is lower than that of the legs due to the higher surface area to mass ratio. Arms have approximately two times the SA/mass ratio as the legs. (9, 26, 64, 67) *(The majority of recognized swim strokes require higher levels of work from arms than legs even at similar workloads. (26, p404).*

8) There is a direct, nonlinear relationship between percent body fat (%BF) and critical water temperature (Tcw) (*Persons with greater % BF have a lower Tcw and therefore can remain longer in the water with less cold stress)*( 3, 4, 7, 8, 9, 16, 24, 25, 28, 34, 35, 38, 42, 44, 49, 53, 59, 60, 62, 64, 65)

9) Performance is affected by water temperature extremes. (46, 47, 50, 64)

It is apparent from these studies that certain temperatures are well outside the range of comfort and therefore inappropriate for swimming instruction. Thus it becomes necessary to find a narrower range for thermal comfort. This can be accomplished by first looking at water temperatures that illicit little or no cold stress responses (head-out, at rest) and work to identify a range of temperatures appropriate for swimming (head- in) and learning to swim at different levels of intensity and for durations appropriate for LTS programming.

***The Lower Limits of Thermal Comfort***

A number of studies have used a three hour immersion (head-out) protocol to established "critical water temperature (Tcw)", defined as the lowest water temperature that an unprotected subject can tolerate at rest without shivering. Sagawa et al. (1988) studied 6 men immersed to the neck *(%BF not given)* and found Tcw to be 31.2±0.5°C. Ferretti et al. (1988) also used a 3 hour immersion protocol to establish an individuals' Tcw and then used Tcw - 6°C to study the effect of exercise (head out immersion) on thermoregulation. Park et al. (1984) established Tcw for their subjects at between 28-32°C before looking at body insulation as it relates to exercise in cool water. Iwamoto et al. (1988) used a 2 hour protocol to establish Tcw. Critical water temperature was established at 32±0.4°C for 9 healthy men with 15.3± 1.2% BF. Bullard and Rapp (1970) suggest that the average Tcw is around 33°C. Cannon and Keatinge (1960) tested men immersed head-out, at rest in increasingly colder water until Tre fell steadily after 2.5 hours and found that metabolic rates increased in water lower than 33°C.

Most LTS programs have a 30 -45 minute class time limit, so a 2-3 hour immersion study may not seem relevant to our discussion. However, the importance lies in considering that instructors may be teaching back to back lessons without re-warming. Studies whose protocols involve shorter (60 minutes or less) durations will have more relevance in establishing guidelines for participants. Carlson et al. (1958) who found that men immersed to the neck for 60 minutes began shivering when water temperatures dropped 2-3°C below control (33°C). Craig and Dvorak (1966) studied men immersed head-out, at rest and found that when water temperatures were below 35°C for a duration of 60 minutes, Tre was lower than for control values. Strong et al. (1985) found that males immersed horizontally at rest in water at 35°C and 32°C for 1 hour at a time showed similar metabolic responses when compared to pre-immersion values. These studies support recommending water temperatures for inactive adults with wide variations in %BF and surface area to mass ratio who are immersed to the neck for an hour in the range of 28 - 35°C.

Again, these temperatures represent a range for inactive, head-out adults but the true challenge of thermoregulation in the water is when the body is fully immersed (submersion) as in swimming, free diving or SCUBA diving. Head submersion increases the cooling rate of the body (22, 51, 52). Pretorius et al. (2006) studied 8 male subjects in Tw at 17°C under four separate conditions; 1)head- out body insulated, 2)head-out, body not insulated, 3)head submerged, body insulated and 4)head submerged, body not insulated. They found that the head which accounts for only 7% of the surface area of the body contributed only 10% of the total body heat loss. However, head submersion increased the cooling rate by an average of 42%. Giesbrecht et al. (2005) reported an increase in body cooling by as much as 40% with head submersion as compared to head-out immersion.

It would seem intuitive that for swimming, thermal comfort may require a higher range of temperatures. However, previous studies have confirmed that a number of factors influence heat loss during immersion. The most significant of these are subcutaneous fat thickness, surface area to mass ratio and immersion at rest versus with exercise, with particular respect to exercise intensity. Therefore, it is important to consider the influence of these factors before establishing guidelines for swimming programs.

### *The role of subcutaneous fat and surface area to mass ratio*

Numerous studies have demonstrated the role of subcutaneous fat thickness in managing cold stress. (3, 4, 7, 35, 42, 47, 54, 59) Body fat has a low thermal conductivity and therefore helps retain body heat (38). Individuals with low %BF cool more quickly than those with high %BF when immersed in cool / cold water. Cannon and Keatinge (1960) found that thin men had a steeper rise in MR (an indication of shivering) than fat men. Wade et al. (1979) reported on men immersed at rest lying on a cot in water at 25.2°C and found a significant correlation between heat flow from the head, neck and torso and subcutaneous fat thickness. Smith and Hanna (1975) determined that the range of Tcw (29 - 31°C) for 14 male subjects was a result of the differences in subcutaneous fat thickness.

Although subcutaneous fat provides significant insulation, body size, (surface area to mass ratio) has also been found to contribute to body heat loss (17, 38, 41, 49, 54, 62, 65). Beckman and Reeves (1966) showed that the rate of heat loss is a function of the amount of surface area exposed to the water and the relative thermal conductivity of that area. Strong et al. (1985) found that small individuals demonstrate a greater increase in tissue insulation and metabolic heat production per decrease in Tre and Tsk than large individuals. This holds true for the amount of surface area exposed to the water as well as the surface area to mass ratio of the extremities. Sagawa et al. (1988) reported that resting heat loss was greater in the limbs than the trunk. Lee et al. (1997) studied men immersed at knee, hip and shoulder levels and found that thermal balance in shoulder level water was not possible in water at 15 or 25°C.

### *The role of exercise*

There is little doubt that at certain temperatures exercise contributes to thermoregulation (13, 26, 32, 36, 43, 44, 50, 57). When a person begins exercising in the water, heat from the working muscles helps maintain thermal balance. To what degree depends not only on the temperature of the water, but to a great degree on the type of exercise and the intensity of the effort (determine as a percentage of $VO_{2max}$).

There is an inverse relationship between water temperature and the intensity of exercise needed to attain / maintain thermal balance. In general, the colder the water (to a point), the higher the intensity needed to maintain thermal equilibrium (13, 32, 43, 44, 58, 66, 67). However, there are also temperatures below which no amount of exercise can keep the core temperature from dropping (26, 27, 32, 41).

Exercise intensity can be expressed in a number of ways, as a percentage of $VO_{2max}$ , in energy equivalents such as METs (metabolic equivalents), milliliters per kilogram per minute, liters per minute, kcal per kilogram per hour and kcal per minutes. Each of these is based on a persons' body weight and therefore difficult to compare from study to study. For the purpose of this discussion we will identify each effort as light, moderate and hard work to simplify comparison when possible.

With light exercise, the range of comfortable temperatures for head out immersion seems to vary between 26 and 32°C. Lee et al. (1997) found that light exercise (leg cycling at 35% $VO_{2max}$) did not maintain Tre in shoulder depth water at 25°C. Choi et al. (1996) studied subjects on a bicycle ergometry at MR corresponding with 60 $kcal \cdot h^{-1} \cdot m^{-2}$ (very light workload). For most subjects in this study, Tre declined in water below 30°C whether during rest or exercise. Craig and Dvorak (1968) reported that during light (.70 l/min) leg work, Tre continued to decline when water was less than 32°C. Pirnay et al. (1997) reported that subjects in their study were able to maintain thermal balance with light and moderate exercise in 26°C. With moderate workloads, it seems that most adults can maintain thermal equilibrium at approximately 25°C for efforts of 30 to 60 minutes (32, 44, 58)

The type of exercise performed in the water is also a variable in thermoregulation. The types of exercises representative of the "head-out" immersion studies include arm exercise such as rowing, or arm cycle ergometry (66, 67 ), leg exercise, the most common of which is a cycle ergometry (9, 13, 26, 32, 41, 44, 50, 65) and a combination of leg and arm exercise (28, 43, 49, 67). It seems that leg exercise results in a smaller fall of Tre with cold immersion or maintains thermal balance when compared to arm exercise at the same level of effort (26, 49, 66, 67).

Efficient swimming requires head submersion and a greater use of the arms. Wade and Veghte (1977) used radiograms to study heat loss areas in swimming subjects in 23°C water. The warmest areas recorded for the non immersion control were in the chest, groin, lower abdomen and neck. After a 500 yard freestyle swim, the warmest areas were the trapezius, deltoids, triceps, biceps brachii and the pectorals (the active swimming muscles). The legs, however, remained cooler. Considering that swimming is a predominantly upper body exercise, it would seem intuitive that temperature ranges for efficient swimming might be somewhat higher especially when compared to ranges for leg dominant, head-out, water exercise protocols.

In swimming (freestyle and breaststroke) research, the most common temperatures in literature are 18°C (30, 47, 64), 21°C (21, 31, 54, 56), 25°C (39, 54, 64, 74), 26°C (11, 30, 46, 47) and 33°C (20, 21, 31, 48, 56, 75). These temperatures have been studied to establish the range for competitive swimming and /or to identify a range of temperatures that affect swimming performance. As would be expected from previously reviewed immersion literature and with all things being equal (surface area to mass ratio, subcutaneous fat thickness and duration of immersion) temperature ranges for swimming are dependent on swimming intensity (30, 31, 47).

Fujishima et al. (2001) looked at thermoregulatory responses to prolonged (120 minutes) breaststroke in 23, 28 and 33°C. Subjects swam at 50% VO2max in 23°C water, 43% VO2max in 28°C water and at 42% VO2max in 33°C. Tres declined in both 23 and 28°C and increased in 33°C water. Robinson and Somers (1971) looked at swimmers swimming freestyle for 60 minutes in water 21, 29 and 33°C. They reported that in 21°C the Tre of the slowest swimmers declined and the average Tre of the fastest swimmers increased slightly. They suggested that optimal water temperature for swimmers was nearer 29°C because at that temperature core and surface temperature gradients were adequate for heat conductance. The findings of Nadal et al. (1974) agree. They suggest that the optimal water temperature for sprint performance is between 28 and 30°C.

Houston et al. (1978) studied male subjects swimming breaststroke for an hour at 65% VO2max in 21, 27, and 33°C. Core and esophageal temperatures tended to rise in 27°C and decreased by a similar magnitude in 21°C. They suggested that competitive swimmers might benefit from the thermal stress presented by 21°C but that recreational swimmers might need at least 27°C to maintain thermal equilibrium. Galbo et al. (1979) confirms these findings. Subjects in this study reported that it was more difficult to swim in 21 and 33°C as compared to 27°C water. In Holmer and Bergh (1974) subjects swam breaststroke in three different water temperatures (18, 26 and 34°C) with two different intensities. They performed a 20 minute submaximal (approximately 50% $VO_{2max}$) effort for 20 minutes and then a maximal test in each water temperature. For all maximal efforts Tes rose exponentially. Tes was lower for both 18 and 26°C with submaximal effort for 20 minutes.

It would appear that water temperature for thermal comfort during light to moderate swimming intensities can range from 27 - 32°C. For maximal efforts that range can vary from 18 - 30°C. Keep in mind that these studies were done with adult subjects. These ranges will need to be adjusted based on age and possibly gender.

***Gender and age***

Adjustments to cold exposure have been found to differ with age and gender (10, 15, 18, 40, 43, 59, 61, 71, 72). Though reasons for this cannot totally be explained, it is clear that children and older adults chill faster than young and middle aged adults and males chill faster than females. Falk (1998) suggests that physical and physiological differences may explain some of the age related adjustments to cold exposure. The two most significant physical differences are surface area to mass ratio and %BF. Children have a higher surface area to mass ratio than adults which increases heat loss. In many instances, young to middle aged adults have a higher % body fat. Both of these physical factors have been shown to increase the cooling rate of children over adults (59, 61, 71).

When comparing young adults (18-30) to older adults (50-72), physiology seems to play a greater role than the physical factors. Falk et al. (1994) compared young adults to trained and untrained seniors at Ta thermoneutral (22°C) and Ta 5°C for 30 minutes at rest and 30 minutes of exercise. Young adults were able to maintain Tre with low intensity exercise, trained and untrained seniors were not. Collins et al. (1985) found that older adults had a significantly greater increase in blood pressures at Ta 6°C than younger adults. LeBlanc et al. (1978) found a significant relationship between $VO_{2max}$ and a fall in skin temperature. They found that subjects with lower $VO_{2max}$ experienced a larger drop in Tsk. Maximal aerobic power decreases with age and a lower $VO_{2max}$ could account for some of the age related differences in cold stress responses. Frank et al. (2000) supports this hypothesis.

***The Upper Limits of Thermal Comfort***

There are warm water temperature limits for thermal comfort as well. Veicsteinas et al. (1982) found that vasodilation (heat dissipation) occurred at water temperatures between 32 -33°C in men immersed head-out at rest for 3 hours. Craig and Dvorak (1966) reported that when water temperature was 36 or 37°C, men showed a continuous increase in the central temperature. Tre also increased with a high work load in 28 - 32°C water. Participants in this study reported feeling most comfortable in 34-36°C and feeling tired and restless at 37°C.

Shimizu et al. (1998) found that Tre rose significantly at 29°C with exercise at 50% VO2 max. Pirnay (1997) also found that sub max levels of exercise (approximately 50% effort) caused hyperthermia in water ≥ 30°C. Costill's (1967) findings (20 minutes of submaximal swimming) suggest that if a person is immersed in water below 32°C he/she will become hypothermic at a rate proportional to the duration of immersion or the difference in the thermal gradient below 32°C.

It would seem appropriate than to have temperature ranges for Aquatic Instructional programs adjusted based on activity level and age of the participant. Younger children and older adults need warmer water for thermal comfort and balance. The lower the intensity of the effort, the higher will be the accepted ranges. Participants learning to swim (low intensity or limited activity) need warmer water than more proficient swimmers, participating at a higher level of intensity. The duration of the lesson will have to be based on the other parameters and also be related to current thoughts about learning theory.

**Overall Recommendation:**

Water temperature is a major factor in participant comfort and overall success of any "Aquatic Instructional" program. Water that is too cold can lead to chilling and discomfort and result in limiting the time spent on necessary practice. Likewise, water too hot can lead to overheating and discomfort in limiting the time spent on necessary practice. In summary, the weight of the evidence suggests that for each person there is a water temperature range in which he/she is most comfortable at rest and at different levels of exercise intensity. The number of possible interactions (age, gender, subcutaneous fat thickness, surface area to mass ratio) makes it nearly impossible to set a specific standard for each person / activity in the water and, therefore, only general guidelines will be given. The most important factor is that Aquatic Instructors are able to recognize when a student needs to end an in or out water session because the early onset of temperature related issues regardless of water temperature.

Based on 9 LOE 2a studies, the recommended water temperature range for adults ages 17-55 immersed with head out of water, at rest, in an indoor pool with controlled humidity and air temperatures for durations ranging from 40 – 120 minutes is 29 - 33°C (84.2 – 91.4F). Adults with either higher subcutaneous fat levels or surface area to mass ratio or both, will tolerate water at the lower end of the range for longer periods of time.

Based on 11 LOE 2a studies, the recommended water temperature range for adults ages 17-55 in an indoor pool with controlled humidity and air temperatures for durations ranging from 20 – 120 minutes of swimming at low intensities is 29° - 32°C (84.2° – 89.6°F). Adults with either higher subcutaneous fat levels or surface area to mass ratio or both, will tolerate water at the lower end of the range for longer periods of time.

Based on 11 LOE 2a studies, the recommended water temperature range for adults ages 17-55 in an indoor pool with controlled humidity and air temperatures for durations ranging from 20 – 120 minutes and swimming at moderate (at least 50% effort) to high intensities is 26° - 28°C (78.8°- 82°F). Adults with either higher subcutaneous fat levels or surface area to mass ratio or both, will tolerate water at the lower end of the range for longer periods of time

Based on 11 LOE 2a studies, the recommended water temperature range for adults ages 17-55 in an indoor pool with controlled humidity and air temperatures for durations ranging from 15 – 135 minutes head out exercise at low to moderate intensities is 26°-28°C (78.8°- 82°F) . Adults with either higher subcutaneous fat levels or surface area to mass ratio or both, will tolerate water at the lower end of the range for longer periods of time

Based on 31 LOE 2a studies, the recommended maximum water temperature range for adults ages 17-55 in an indoor pool with controlled humidity and air temperatures for durations ranging from 15 – 135 minutes at rest or with low intensity exercise is ≤ 32°C (89.6°F). Adults with either higher subcutaneous fat levels or surface area to mass ratio or both, may not tolerate water at 32°C (89.6°F) for long periods of time. Watch for signs of hyperthermia. (For moderate (at least 50% $V0_{2max}$) or higher intensities water temperature should not exceed 27°C (80.6°F)

**Recommendations and Strength:**

**Standards:**

None

**Guidelines:**

Based on studies in a controlled environment (defined as an indoor pool with controlled humidity and air temperature), and with most of the consideration given to the level of intensity of the activity (as the activity intensity increases thermal balance can be achieved at the lower end of the range) and the immersion time (as immersion time increases core temperature decreases)

Infant / preschool aquatics (20 to 30 minutes*)
Water temperature - water temperature should be ≥32° C (89.6º F)

Learn to swim up to ages 6- 15 (30 to 45 minutes*)
Water temperature - water temperature should be ≥ 29° C (84.2º F)

Junior Lifeguard ages 11-14 (45 to 60 minutes*)
Water temperature water temperature should be ≥29° C (84.2º F)

Lifeguard training up to ages 15 – 55 (60 to 120 minutes*)
Low intensity activity-water temperature should be 29° to 32°C (84.2° to 89.6 F)
Intense activity – water temperature should be 26° to 28° C (78.8° to 82° F)

Water Safety Instructor up to ages16- 55 (60 – 120 minutes*)
Low intensity activity-water temperature should be 29° to 32°C (84.2 ° to 89.6°F)
Intense activity – water temperature should be 26° to 28°C (78.8° to 82° F)

* Student immersion time per session.

**Options:**
Instructors should watch for signs of hypothermia or hyperthermia as an indication that it is time to end the session. For water temperatures below the recommended ranges the following options are suggested:

1) Add clothing that does not compromise safety (5 LOE 2a studies )
2) Covering the head that does not compromise safety (3 LOE 2a studies)
3) Limit the amount of time in the water

**Summary of Key Articles/Literature Found and Level of Evidence:**

| | **Author(s)** | **Full Citation** | **Summary of Article (provide a brief summary of what the article adds to this review)** | **Level of Evidence** |
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| 1 | American National Red Cross | Water Safety Instructor Manual. American National Red Cross 2009 | p. 115 "Maintain a water temperature of at least 83°F (28.3°C)". p. 148. "Typically, water temperature that is at least 83°F (28.3°C) is more comfortable for young children". | 5 |
| 2 | Aquatic Exercise Association | 2010 Standards & Guidelines: Aquatic Fitness Programming. Aquatic Exercise Association 2010 | p.3 "Children, fitness 83-86F / 28.3 – 30C" "Children, swim lessons 84+F/ 28.9+C *Varies with age, class length, and programming; ideal learn to swim programs is best suited for 84-89F / 28.9-31.7C when available" "Infant programs (4 and under) 90-93F / 32.2 – 33.9C * (USA Swimming) | 5 |
| 3 | Beckman EL, Reeves E | Physiological implications as to survival during immersion in water at 75° F. Beckman EL, Reeves E. Aerospace Medicine. Nov. 1966, 1136-1142 | N=24 males were immersed to the neck in a life vest in water @ 75°F for 2-4 hours, 4-8 hours or 8-12 hours. Only 6 subjects completed the full 12 hours. The rate of body heat loss is directly related to specific gravity and inversely related to %BF. Rate of heat loss is primarily a function of the area of the body exposed to the cold water and the thermal conductivity of that area. Adipose tissue has a lower thermal conductivity than muscle and skin. Subjects with the lowest specific gravity were the ones who stayed in the water for the full 12 hours. | 2a |
| 4 | Boutelier C, Bougues L, | Experimental study of convective heat transfer | N= 17 male subjects were immersed supine with the face out in water | 2a |

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| | Timbal J | coefficient for the human body in water. Boutelier C, Bougues L, Timbal J, J Appl Physiol:: Respirat Enviorn Exercise Physiol 1977. 42 (1): 93-100 | ranging from 33.7 to 18°C at water velocities between 0 and 0.25 m/s. The skin to water (ΔT) gradient decreases when water velocity increases. Shivering intensity at the same water velocity and temperature conditions varies with the fat layer thicknesses of the subjects. | |
| 5 | Bullard RW, Rapp GM | Problems of body heat loss in water immersion. Bullard RW, Rapp GM. Aerospace Med.1970 41(11): 1269-1277. | This is a review article using a model for developing concepts of heat loss in water immersion. Heat energy flows down the temperature gradient (Tc – Tsk followed by Tsk – Tw) from trunk to extremities to the cooler water. The flow of heat energy is resisted by body structural components and aided by blood circulation. The resistance to heat flow is very low when compared to air and becomes even lower if water and skin are in motion with respect to each other. A thermogenic response occurs by lowering temperatures. Metabolic rate increases (shivering theromogensis). Any type of muscle activity (exercise) by the extremities increases heat conductance (*k*) because blood flow increases to the exercising limbs and there is more surface area to dissipate heat.<br>The average critical water temperature (Tcw) is around 33°C. There is a great deal of variation found in immersion experiments. Subcutaneous fat accounts for a major portion of such variation. Physical condition determines the ability to maintain a high metabolic rate and attain thermal equilibrium. | 2a |
| 6 | Cabanac, M | Temperature Regulation. Cabanac, M. Annual Rev Physiol 1975 37: 415-439 | The term “temperature regulation” means that there are mechanisms defending the temperature of one or several definable regions of the body. Basic patterns of thermoregulatory responses include a) heat production through shivering and other metabolic | 2a |

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| | | | processes and b) vasomotor responses resulting in heat transfer from core to skin and, in turn, of heat loss to the environment. It has been confirmed in experimental studies that skin vaso constriction is a cold defense reaction and skin vasodilation as a warm defense reaction were compensated by simultaneous opposite responses in the thermal core. In man, direct measurement of hypothalamic temperature is not possible, nor is independent stimulation of various internal sensors. Thus, the only combination that can be investigated in man is the interaction between mean Tsk and internal Tre or Tcore temperatures | |
| 7 | Cannon P, Keatinge WR | "The metabolic rate and heat loss of fat and thin men in heat balance in cold and warm water." Cannon P, Keatinge WR, J Physiol 1960 154: 329-344 | The purpose of this study was to determine whether work assisted in maintenance of Tb in water too cold to maintain thermal equilibrium while stationary. N = 8 healthy navy men ages 17-21, wearing a fleece lined helmet covering much of the face and immersed to the shoulders at progressively lower temperatures until Tre fell steadily after 2.5 hours. Five men were then immersed at the next lowest temperature and told to work as hard as they could. Metabolic rate of each man began to increase when Tw was lowered below 33°C. Rise in MR was steeper for thin vs fat men. For the 5 subjects immersed in the lower Tw, Tre fell more rapidly during work than at rest. | 2a |
| 8 | Carlson LD, Hsieh ACL, Fullerton F, Elsner RW | Immersion in cold water and body tissue insulation. Carlson LD, Hsieh ACL, Fullerton F, Elsner RW. Aviation Medicine, February 1958 145-152. | N= 9 men immersed to the neck for one hour in 33, 25 and 20°C. Oxygen consumption with temperature drop indicates that subjects with a decrease in insulation began shivering between 4-5 minutes after the bath temp dropped 2-3°C (from 33°C). Body | 2a |

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| | | | insulation varied with specific gravity. | |
| 9 | Choi JS, Ahn, DW, Choi JK, Kim KR, Park YS | Thermal balance of man in water: prediction of deep body temperature change. Choi JS, Ahn, DW, Choi JK, Kim KR, Park YS. Appl Human Sci 1996; 15(4): 161-167. | N = 12 healthy males with SCF of between 2.4 to 8.0 mm. Subjects were dressed in swim suits and immersed up to the neck in Tw @ 15,20,25,30 or 35° C for 1 hour. An external workload that could increase MR by 60 $kcal \cdot h^{-1} \cdot m^{-2}$ was established empirically. Tre fell linearly with time after approximately 20 min. Rate of fall was greater with lower temperatures.<br>During exercise on a bicycle ergometer, Tre remained the same for the first 15 minutes and then declined steadily. At any given Tw, the deep body cooling rate was significantly lower during exercise than at rest. The general patterns of cold immersion responses were similar but varied considerably with %BF.<br>For most subjects in this study Tre declined in Tw below 30°C, regardless of whether they were resting or exercising. In the present study the cooling rate was considerably smaller with exercise than at rest. | 2a |
| 10 | Collins KJ, Easton JC, Belfield-Smith H, Exton-Smith AN, Pluck RA | Effects of age on body temperature and blood pressure in cold environments. Collins KJ, Easton JC, Belfield-Smith H, Exton-Smith AN, Pluck RA. Clinical Science 1985; 69: 465-470 | N = 9 subjects (5 in age range 63-70 and 4 in age range 18-24 years) were exposed to Ta @ 6, 9, 12, 15, and 23°C. (air blown over the body surface at 0.5 m/s) four hours/day for 7-10 days. Subjects wore standard open-collar battledress, shirt, underclothes and civilian shoes (1.5 CLO) and remained seated during the exposure. There was no evidence of acclimation in either group. The fall in core temperature was significantly greater at 6°C for older than younger subjects. No significant differences of thermal comfort sensation were found @ Tw 15, 12, 9 and 6°C.<br>There was a significant increase in BP @ 6°C and was greater in old than in | 2a<br>2aE |

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| | | | the young. At 15°C there were no significant changes in BP in either group. HR decreased sharply over the first 15 minutes for the young in 6°C, with older subjects experiencing a steady falling HR in 6 and 12°C. At 15°C, there were no significant HR changes in either group. | |
| 11 | Costill D L, Cahill PJ, Eddy D | Metabolic responses to submaximal exercise in three water temperatures. Costill DL, Cahill PJ, Eddy D. J Appl Physiol. 1967 22(4): 628-632 | In Tw 17.4°, 26.8° & 33.1°C, 8 men, (mean age 21.13, mean %BF 7.7) participated in submaximal swimming for 20 minutes. Tsk during exercise remained higher than Tw in all cases but thermal differential was inversely related. Mean Tre increase during exercise was greatest @ 33.1°C and least @ 17.4°C. Tre decreased during recovery more rapidly in 17.4°C than in 26.8°C. Tre decrease at 17.4 was lower than pre-immersion Tre. | 2a |
| 12 | Craig AB, Dvorak M | Thermal regulation during water immersion. Craig, A B, Dvoak M. J Appl Physiol, 1966 21(5): 1577 1585 | N= 10 men immersed for one hour, semi recumbent with water just below the chin in Tw @ (24, 26, 28, 30, 32, 34, 36 and 37°C. When Tw was 36 or 37°C, there was a continuous increase in central temperature. In Tw @ 35°C or lower, Tc were below control values at the end of 60 minutes. In Tw @ 30°C or less, there was an initial rise in Tre. $V0_2$ would increase in water less than 30°C if time was approximately 40 minutes or less. Subjective observations: subjects were most comfortable in 34-36°C; tired and restless at 37°C; cold initially at 30 and 32°C but feelings passed in the first 3-5 minutes; 28°C seemed the hardest to tolerate; 24 and 26°C didn't seem so difficult after initial responses to immersion. | 2a |
| 13 | Craig AB, Dvorak M | Thermal regulation of man exercising during water immersion. Craig AB, Dvorak M. J Appl Physiol 1968. 25 (1) 28-35. | N=10 male subjects exercised at two workloads (light =.70 l/min; heavy .92 l/min) on a bicycle ergometer nearly horizontal, and immersed with the head out in Tw @ 24, 26, 28, 30, 31 and | 2a |

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| | | | 32°C. With light work, Tre continues to decline in Tw less than 32°C. At high workload the initial decrease in Tre was followed by an increase when water temperature was 28-32°C.<br>With light workload the Ts necessary to prevent ΔTre would be 34°C for subjects whose heat production is approximately 2.5X resting. For heavy workloads, an equivalent Tw would be approximately 29°C. | |
| 14 | Falk B | Effects of thermal stress during rest and exercise in the paediatric population. Falk B, Sports Med 1998 Apr; 25(4): 221-40 | This is a review of age related differences in the human thermoregulatory system. Physical and physiological differences between children and adults may explain the differences in thermoregulation. The main physical difference is the higher surface area-to-mass ratio of children. This increases heat loss. The main physiological difference btw adults and children is the sweating mechanism, affecting thermoregulation in the heat but not in the cold. Children have a higher metabolic cost of locomotion that may be advantageous in the cold by increasing heat production.<br>In Tn temperatures, children have similar rectal temperatures but higher skin temps. In a cold environment, children have lower skin temperatures as compared to adults, indicating greater vasoconstriction. Metabolic heat is also greater in the cold for children than adults. | 3 |
| 15 | Falk B, Bar-or O, Smolander J, and Frost G | Response to rest and exercise in the cold: effects of age and aerobic fitness. Falk B, Bar-or O, Smolander J, and Frost G. J Appl Physiol, 1994. 76(1): 72-78 | N = 3 groups of healthy men: 1) 8 young adults (YA), ages 21-29, 2) 8 well trained seniors (TS), ages 55-66 and 3) 11 untrained seniors (different $VO_{2max}$ than TS) with no significant differences in anthropometric measures. Subjects were exposed to 20 minutes @ themoneutral (22°C), 10 minutes at rest and 10 minutes cycle at a pre-determined work rate | 2a |

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| | | | (approximately 50 W which is equivalent to most occupational activities). After 1-hr of rest they were exposed to 5°C for 30 minutes of rest and then 30 minutes at the same work rate as the thermoneutral trial.<br>The findings in this study show an age-related diminished ability to maintain core temperature during rest and low intensity exercise in the cold. YA were able to maintain Tre with this work rate but TS and US were not. | |
| 16 | Farnell G, Pierce J, Demes R, Collingsworth T, Ryan EJ, Bellar D, Bliss MV, Barkley JE, Kamimori GH, Glickman EL | Effects of body composition on thermoregulatory responses during cold water immersion in healthy males. Farnell G, Pierce J, Demes R, Collingsworth T, Ryan EJ, Bellar D, Bliss MV, Barkley JE, Kamimori GH, Glickman EL. Med Sci Sport Exercise, 2008 40(5):S228 | N= 6 low fat (LF, 10.1±1.4%BF) and 5 high fat (HF, 28.1±3.5%BF) were immersed to the neck in water @ 18, 22, 26°C for a baseline of 10 minutes, followed by 120 minute immersion and a 15 minute re-warming period on a cycle ergometer.<br>LF subjects had a greater decrease in Tre and greater increases in $V0_2$ over time compared with HF subjects. High fat subjects tolerated cold water immersion more efficiently and effectively than LF individuals. | 2a |
| 17 | Ferretti G, Veicsteinas A, Rennie, DW | Reginal heat flows of resting and exercising man immersed in cool water. Ferretti G, Veicsteinas A, Rennie DW. J Appl Physiol 1988, 64(3): 1239-1248 | N= 9 men immersed to the neck in Tw ranging from 22-32°C. This study included 3 Protocols: 1) 3 hours at rest @ Tw below Tcw 2) 3 hours with light exercise (30% $V0_{2\ max}$ and 3) 3 hours with heavy exercise @ Tw below Tcw (70% $V0_{2max}$). Subjects were only able to remain immersed 80-170 minutes due to onset of shivering.<br>The temperature at which thermal balance is reached in a 3 hour immersion is Tw = Tcw + 1.5°C<br>Exercise in the water may increase core temperature depending on the intensity of the exercise, body obesity, area to body weight ratio and whether or not the limbs are being exercised. There is a preferential heat exchange from the limbs to water because of the greater percentage of total body area in | 2a |

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| | | | comparrison to the trunk. Circulation to the limbs is reduced to a minimum in Tcw. | |
| 18 | Frank SM, Jaja A, Bulcao C, Goldstein DS. | Age-related thermoregulatory differences during core cooling in humans. Frank SM, Jaja A, Bulcao C, Goldstein DS. Am J Physiol, 2000; 279: R349-354 | N = 8 younger subjects (18-23) and 8 older subjects (55-71) were given a cold fluid intraveneously over a period of 30 minutes to compare Tre thresholds for vasoconstriction, heat production (shivering) and perceived thermal comfort among other things. Older subjects had a significantly greater %BF. Maximum intensities of both vasoconstriction and total body $O^2$ consumption were less in the older group. Mean maximum shivering score was lower in the older group. Subjective thermal comfort scores were similar in the two age groups despite the lower Tc in the older group. The results indicate that all three major cold responses are in some way impaired with age. | 2a |
| 19 | Froese G and Burton AC | Heat losses from the human head. Froese G and Burton AC. J Appl Physiol 1957, 10(2): 235-241 | This study measured the nonevaporative heat loss of N = 3 subjects, with unprotected heads but adequately clothed bodies, at temperatures between 32° C and -21°C. The tissue insulation of the head apprears to be constant over a wide range of temperatures. The findings support the point that there is little or no vasoconstriction in the head in repsonse to cold. It can be estimated from this study that for an average resting subject, the heat balance of the head (heat loss balanced by heat production) occurs at around 22°C (71.6°F). | 2a |
| 20 | Fujishima K, Shimizu T, Ogaki T, Hotta N, Kanaya S, Shono T, Ueda T | Thermoregulatory responses to low-intensity prolonged swimming in water at various temperatures and treadmill walking on land. Fujishima K, Shimizu T, | N=6 male college swimmers (age 19.8±0.9 and % BF 13.2±3.4) swam 120 minutes of breaststroke in a swim flume at a constant speed of 0.4m/sec-1, (approximately 50% $VO_2$ max @ 23°, 43% max @ 28° and 42% max @ | 2a |

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| | | Ogaki T, Hotta N, Kanaya S, Shono T, Ueda T. J Physiol Anthropol, 2001 20(3):199-206 | 33°C).<br>Tre steadily declined and was significant after 20 minutes @ 23 & 28<br>Tre during swimming in 23 and 28°C decreased significantly compared to temperatures at rest in air. There was no significant change in the 33°C trial compared to air | |
| 21 | Galbo H, Houston ME, Christensen NJ, Holst JJ, Nielsen B, Nygaard E, and Suzuki J | The effect of water temperature on the hormonal response to prolonged swimming. Galbo H, Houston ME, Christensen NJ, Holst JJ, Nielsen B, Nygaard E, and Suzuki J Acta Physiol Scand, 1979 105: 326-337 | N=6 men swimming breaststroke for 60 minutes at a speed requiring 65% $VO_{2\ max}$ (determined in 27°C water) @ 21°, 27° and 33°C.<br>Tre increased significantly in 33° and to a smaller extent in 27°C.<br>Tre decreased in 21°C<br>Swimmers perceived that 21°C was too cold and felt "enclosed in heat in 33°C and found it more difficult to complete the swim at these temps than @ 27°C | 2a |
| 22 | Giesbrecht GG, Lockhert TL, Bristow GK, and Steinman AM | Thermal effects of dorsal head immersion in cold water on nonshivering humans. Giesbrecht GG, Lockhert TL, Bristow GK, and Steinman AM. J Appl Physiol, 2005 99: 1958-1964 | N = 6 male volunteers were immersed 4 times for up to 60 minutes in 12°C water. An insulated hoodless dry suit or two different floatation devices was used to create four conditions: 1) body insulated, head out, 2) body insulated, dorsal head immersion, 3) body exposed, head and upper chest out, 4) body exposed and dorsal head immersion and chest immersion.<br>When the body was insulated, dorsal head immersion did not affect core cooling rate compared with head-out conditions. When the body was exposed, the core cooling rate increased by 40% from head out condition to dorsal head and upper chest immersed. | 2a |
| 23 | Glickman EL, Caine-Bish N, Cheatham CC, Blegen M, Potkanowicz ES, | The influence of age on thermosensitivity during cold water immersion. Glickman EL, Caine-Bish N, Cheatham CC, Blegen M, Potkanowicz ES, Wilderness and Environ | N = 15 young men (YNG, 18-30 and % BF 10.9±2.9) and 7 old men (OLD, 40-55 and %BF 13.7±8.4) were immersed to the first thoracic vertebrae, with limbs separated in Tw @ 20°C for 3 phases over a 60 minute period to determine if there are | 2a |

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| | | Med. 2002 Fall; 13(3):194-202 | significant differences in heat production (HP), esophogeal temperature (Tes), mean skin temperature (Tsk), and central thermosensitivity (defined as an increase in HP with controlled manipulation of Tes).<br>Tre declined in both age groups at rest in 21°C water.<br>This study found that YNG and OLD subjects responded similarly in all responses to Tw @ 20°C. | |
| 24 | Glickman-Weiss EL, Goss FL, Robertson RJ, Metz KF, Cassinelli DA | Physiological and thermal responses of males with varying body compositions during immersion in moderately cold water. Glickman-Weiss E L, Goss F L, Robertson R J, Metz K F, Cassinelli D A. Aviat Space Environ Med 1991, 62: 1063-1067 | N = 24 male volunteers, ages 20-35 (12 low fat subjects; 9-12%BF and 12 high fat subjects; 18-22%BF) immersed to the first thoracic vertebrae and randomly assigned for a 90 minute immersion in one of 3 Tw (18, 22 or 26°C).<br>After the first 5 minutes, Tsk approached Tw and remained unchanged in both groups.<br>Tre delcined as a function of time and were similare for all subjects at each time pont over the 90 minutes.<br>This investigation demonstrated that the magnitude of the increase in $V0_2$ during cold water immersion is primarily influenced by the physiological characteristics of the subjects. LF subjects typically have a greater $0_2$ response than HF subjects. | 2a |
| 25 | Glickman-Weiss EL, Nelson AG, Hearon CM, Goss² FL, Robertson² RJ, Cassinelli DA | Effects of body morphology and mass on thermal responses to cold water: revisited. Glickman-Weiss EL, Nelson AG, Hearon CM, Goss² FL, Robertson² RJ, Cassinelli DA. Eur J Appl Physiol. 1993, 66: 299-303 | N= 7 males college students (4 with large mass and %BF 14.5±4.1) and 3 with small mass and %BF 16.5±3.5)), with similar total body fat, were immersed to the first thoracic vertebrae for 120 minutes in stirred water @ 18°C.<br>Tre declined for all subjects as a function of time.<br>Tissue insulation was higher in LM subjects compared to SM subjects (non-significant differences). After 5 minutes Tsk approached Tw and | 2a |

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| | | | remained unchanged for both groups throughout the experiment. There were no differences between groups in $V0_2$ response, thermal sensation response or tissue insulation. Differences in surface area to mass ratio did not result in significant differences in heat loss during rest in cold water. | |
| 26 | Golden F St.C, Tipton MJ | Human thermal responses during leg only exercise in cold water. Golden F St.C, Tipton MJ J Physiol 1987; 391-401 | N = 15 healthy male subjects (btw ages 17 and 34) performed two 40 minute head-out immersions in Tw @ 15°C. One trial was dynamic immersion (leg exercise on a modified bicycle ergometer, working at the same relative workload; $VO_2$ 1·8 l $O_2min^{-1}$) and one static immersion. The results are for the period between minutes 10 and 30 and compare static immersion to dynamic immersion. Mean Tsk did not differ until minute 30 then was higher for static immersion. Tre fell by a greater amount in static v dynamic immersion. The 'leg-only' exercise in this study resulted in smaller falls in Tre when compared to an equivalent static immersion. | 2a |
| 27 | Hayward JS, Collis M, Eckerson JD | Thermographic evaluation of relative heat loss areas of man during cold water immersion. Aerosp Med 1973 Jul; 44(7): 708-711 | 4 male subjects were immersed in 7.5°C water for 15 minutes, at rest (holding a life ring) and swimming a "semi-backstroke" with a sculling motion of the arms.<br>In all instances, the warmest areas were the trunk and upper arms. The legs were generally cooler. It appears that the greatest heat loss areas during static immersion are the lateral thorax, upper chest and back and groin. During swimming there was higher heat loss in those same areas. | 2a |
| 28 | Hayward MG, Keatinge WR | Roles of subcutaneous fat and thermoregulatory reflexes in determining ability to stabilize body temperature in the water. Hayward MG, Keatinge | N = 14 adult men and women, ages 18-27 were repeatedly immersed in water (including a water spray over the head to simulate total immersion) in decreasing water temperatures until Tre stabilized or dropped below 35°C. | 2a |

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| | | WR. J Physiol. 1981, 320: 229-251 | After establishing the lowest Tw at rest, subjects performed a rowing type motion while pedaling a bicycle during a 30 minute immersion. The lowest Tw in which different young adults could stabilize Tb was found to vary from 32°C to less than 12°C (due to large differences in both total body insulation and metabolic heat production). Total body insulation per unit surface area, in the coldest water allowing stability, was quite closely determined by mean subcutaneous fat thickness, regardless of differences in distribution of fat between men and women. At rest, subjects with larger SCF thickness could generally stabilize Tb in colder water. Exercise reduced internal insulation only in muscular parts and increased heat loss by exposing more skin surface. | |
| 29 | Hayward JS, Eckerson JD, Collis ML | Thermal balance and survival time prediction of man in cold water. Hayward JS, Eckerson JD, Collis ML. J Physiol Pharmacol 1975 53: 21-32 | N= 6 male and 6 female subjects ages 19-29, immersed at rest with a Kapok vest and light clothing in Tw@ 4.6, 10.5 and 18.2°C and slow swimming @ 10.5°C for 25-60 minutes (determined by Tw and limited by Tre of 35.0°C or less).<br>Hypothermia resulted in all conditions while at rest. Hypothetic zero heat production occurs at Tw 38°C and is less than 1°C greater than actual Tre. Extrapolation of this regression to zero cooling rate occurs at Tw 23.1°C (critical temperature). Cooling rate was found to be 35% higher while swimming at 10.5°C. | 2a |
| 30 | Holmer I, Bergh U | Metabolic and thermal responses to swimming in varying temperatures. Holmer I, Bergh U. J Appl Physiol. 1974 37(5): 702-705 | N = 5 swam at 50% $VO_2$ max (determined by max test) for 20 minutes in water @ 18°, 26°and 34°C and then performed a test at maximum intensity.<br>Tes rose exponentially in 26 and 34°C with maximal work.<br>Tes rose in 34°C for the submaximal | 2a |

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| | | | test and was lower in 18°C in 4 of 5 subjects.<br>Tes in 18° and 26°C was found to be related to the thickness of subcutaneous fat.<br>The leanest subject (%BF 3.8) could not sustain Tes with submaximal work in 26 or 18°C. Subjects whose %BF was ≥ 6.2 maintained Tes in 26°C with submaximal work.<br>This study shows that there is a temp that is best for each person but for leaner subjects it is higher than 18-20°C. | |
| 31 | Houston ME, Christensen NJ, Galbo H, Holst JJ, Nielsen B, Nygaard E, Saltin B | Metabolic responses to swimming at three different water temperatures. In Eriksson B, Furberg E, eds. Swimming Medicine IV. University Park Press, 1978. Baltimore, 327-333 | N = 6 male subjects swam in Tw @ 21, 27 and 33°C, for 1 hour using breaststroke at a speed that equated to 65% of their swimming $VO_{2\ max}$.<br>Tc and Tes tended to rise in Tw @ 27°C and decreased by the same magnitude in Tw @ 21°C. Both Tc and Tes rose in 33°C water. HRs for swimming gradually increased over time for Tw 27 and 33°C but were lowest in Tw 21°C. Mean blood lactate levels were highest in Tw 21°C as was $VO_{2\ max}$.<br>Blood metabolites, plasma insulin, and plasma levels of both noradrenaline and adrenaline responses were typical of other forms of submaximal exercise. For competitive swimming the thermal stress presented by 21°C could augment training. However, for recreational swimming, 27°C seems most advisable for maintaining thermal balance. | 2a |
| 32 | Isreal DJ, Heyson KM, Edlich RF, Pozos RS, and Wittmers LE | Core temperature response to immersed bicycle ergometer exercise at water temperatures of 21°, 25°, and 29°C. Isreal DJ, Heyson KM, Edlich RF, Pozos RS, and Wittmers LE. J Burn Care Rehabil 1989, Jul- | N = 5 male volunteers (%BF 14.8±5.6) were immersed to the neck at rest and during exercise on a bicycle ergometer, (predetermined exercise intensity: 63%±0.6% $V0_{2\ max}$) for 30 minutes in Tw @ 21, 25, and 29°C. $V0_2$ was significantly higher during static immersion in all Tws. Exercise $V0_2$s | 2a |

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| | | Aug;10(4):336-45 | for all conditions were statistically similar except in 21°C where $V0_2$ was 3% higher than in 25° and 29°C. Tre where significantly different with static immersion than for exercise immersion in all Tws. Tre rose significantly in Tw @ 29°C, there was little or no rise at 25°C and a nonsignificant decrease in 21°C.<br><br>Ts dropped in the first 5 minutes to within 1°C of Tw in all immersion conditions. A rating of thermal comfort (RTC) designed by the authors showed that during static immersion at all Tws RTC paralleled Ts and did not reflect changes in Tr. In Tw @ 21°C, cycling caused an additional drop in Ts. Subjects' perceptions of thermal comfort may not accurately reflect Tr, ie: people participating immersion activities may not be aware that they have hypothermia.<br>$V0_2$ during static conditions indicates that subjects were shivering in the colder water. RPE was not significantly different between any of the exercise conditions.<br><br>Despite the variation in %BF the temperature change patterns were similar. | |
| 33 | Iwamoto J, Sagawa S, Tajima F, Miki K, Shiraki K | Critical water temperature during water immersion at various atmospheric pressures. Iwamoto J, Sagawa S, Tajima F, Miki K, Shiraki K, J Appl Physiol., 1988; 64(6): 2444-2448, | Critical water temperature defined as the lowest water temperature an unprotected subject can tolerate at rest for 2 hours without shivering. Shivering was defined as 10 minutes of visible tremor accompanied by more than a 15% increase in $V0_2$. N = 9 healthy males, ages 23-36 were immersed at rest. Mean %BF was 15.3 ± 1.2%. Critical Temperature established at 0.6 ATA was 32 ± 0.4°C. | 2a |
| 34 | Jacobs I, Romet | Effects of endurance fitness | N = 9 male volunteers donned standard | 2a |

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| | T, Frim J, Hynes A | on response to cold water immersion. Jacobs I, Romet T, Frim J, Hynes A. Aviat Space Environ Med 1984; 55: 715-720 | flight gear were immersed in Tw@10°C with a lifejacket and remained head out until the Tre dropped 1°C. Immersion time ranged from 21 – 62 minutes and was directly related to %BF. Metabolic values ranged from 1.969-5.110 METs. The length of time of immersion was directly related to endurance fitness level as determined by blood lactate response to submaximal exercise. | |
| 35 | Keatinge WR | The effects of subcutaneous fat and of previous exposure to cold on the body temperature, peripheral blood flow and metabolic rate of men in cold water. Keatinge WR. J Physiol. 1960; 153: 166-178 | N = 12 men, mean age 20.3 were repeatedly immersed to the shoulder for 30 minutes at a time in Tw @ 15 ± 0.1°C. Tsk fell in the first 2 minutes to within 1°C of Tw. The decrease in Tre varied little in successive immersions and was closely related to subcutaneous fat thickness. In the last 20 minutes of immersion, the metabolic rates of thin men increased substantially over those of fat men. Metabolic rate increased with exposure to cold air prior to immersion. | 2a |
| 36 | Keatinge WR | The effect of work and clothing on the maintenance of the body temperature in water. Keatinge WR. Q J Exp Physiol 1961; 46: 69-82 | N = 12 young naval ratings (ages 19-26) were immersed repeatedly to the neck using 4 protocols in Tw @ 5, 15, 25, 35, and 37.8°C. 1) clothed @ work; 2) clothed, still; 3) unclothed (wearing a cotton brief) @ work; 4) unclothed, still. Immersion in the higher temperatures were all unclothed.<br><br>Work consisted of a rowing motion (in water rowing ergometer) at a standard rate of 22 movements per minute or for maximum rate, as rapidly as possible. Clothing consisted of long woolen pants a string vest, submariner's jersey, arctic Jacket and trousers (kapok lined), sea-boot stockings, half-wellington rubber boots, mitts and a leather helmet to protect the neck. Results of 20 minute immersion in 15°C: mean Tsk was within 0.6°C of | 2a |

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| | | | Tw in unclothed, still and similar with unclothed @ work. Tsk was 5°C higher with clothed, still but not as effective clothed, @ work. Tre fell twice as fast with work unclothed than still. Clothing reduced the fall in Tre both still and @ work.<br>Results of 20 minutes of immersion in higher temperatures: Tsk were dependent on Tw but were higher for @ work than still protocols. Tre fell in both 25 and 35°C with still protocols. Work did not affect fall in mean Tb @ 25°C but reversed the small fall in Tw@ 35°C.<br>In other experiments: N = 12 men worked at their highest rate in Tw @ 15°C, Tre fell less than work at a standard rate but still fell faster than with the still protocol.<br>Tsk fell less regardless of clothed/unclothed protocol in unstirred water than in stirred water.<br>The major finding in this study was that Tre fell with work in water below 25°C. Also, clothing gave a substantial amount of protection when subjects were still as opposed to exercise. | |
| 37 | Kenny GP, Denis PM, Proulx CE, Giesbrecht GG | The effect of dynamic exercise on resting cold thermoregulatory responses measured during water immersion. Kenny GP, Denis PM, Proulx CE, Giesbrecht GG. Eur J Appl Physiol. 1999 79: 495-499 | N = 6 males and 1 female, mean age 24(3) and %BF 12.9(1.7)% immersed at rest, to the clavicle at Tw 37.5°C and cooled at a rate of 6.5°C per hour until thresholds of vasoconstriction and shivering were clearly established. Onset of vasoconstriction was found to be Tsk approx 33°C, Tes approx 37°C. Onset of shivering was found to be Tsk approx 30.62° and Tes approx 36.47° | 2a |
| 38 | Kollias J, Barlett l, Beigsteinova V, Skinner JS, Buskirk ER, and Nicholas WC | Metabolic and thermal responses of women during cooling in water. Kollias J, Barlett l, Beigsteinova V, Skinner JS, Buskirk ER, and Nicholas WC, J Appl Physio 1974. 36(5): 577-580 | N = 10 college women (3 lean – 21-24%BF and 7 obese – 29-41%BF) sat immersed to the neck in Tw 20°C for 60 minutes (limits: voluntary withdraw or 2°C drop in core temperature). Obese woman were taller, 53% heavier, fatter and had a | 2a |

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| | | | lower surface area-to-mass ratio than lean subjects. Within 15 minutes of immersion metabolic rate for lean subjects had increased 2-3 X. Rate of ΔTre was greater for lean than for obese.<br>Tre for obese rose ove the 1st 15 min and then slower declined. Tre for lean subjects declined 1.4°C as compared to 0.4°C by obese subjects.<br>Also found that average Tre was lower after participation (N=5) in a weight loss program, with decreases in BW btw 3.7 -6.7kg. | |
| 39 | Lapp MC, Gee GK | Human acclimatization to cold water immersion. Lapp MC, Gee GK. Arch Environ Health 1967 15 (11): 568-579 | N= 8 (3 male, 5 female) were immersed at rest, 2 X /wk for 1 hour over an 8 wk period @ selected bath temperatures of 21.1, 23.3, 25.6, 27.8 and 30°C<br>The greater the body surface area the greater the rate of body heat loss.<br>When bath temperatures ranged from 30°C(86F) to 28.3°C (83F), subjects did not mind the immersion experience.<br>Shivering was observed for the first time in water @ 28.3°C and generally occurred after 20-30 minutes.<br>Shivering threshold for subjects in this study was found to be established at a differential of 8.5°C (15.3F) between Tre and Tw.<br>Temperatures from 23.9°C (75F to 21.1°C(70F) indicate a loss of effectiveness of the thermoregulatory mechanism.<br>Body surface area appeared to be a significant factor in heat loss at this temperature range. | 2a |
| 40 | LeBlanc J, Cote J, Dulca S, and Dulong-Turcot F | Effects of age, sex and physical fitness on responses to local cooling. LeBlanc J, Cote J, Dulca S, and Dulong-Turcot F. J Appl Physiol 1978; 44: 813-817 | This study aimed at explaining some of the individual variability observed in large groups of subjects. In all, three experiments were carried out. N = 27 males to assess the influence of fitness; N = 9 subjects (20-47yrs) and 8 (53-60 | 2a |

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| | | | yrs) to assess the influence of age; N= 9 males (average age 35.0) and 8 females (average age 30.4) to assess the influence of gender.<br>All subjects were tested with a cold hand test (placing the hand in water a 5°C for 2 minutes) and a cold face test (cold wind, 0°C blown on the face at 66 km·h$^{-1}$)<br>A significant relationship was found between $VO_{2\ max}$ and fall in Tsk. The lower the $VO_{2\ max}$, the larger the fall in Tsk. HR increased during the cold hand test but was significantly reduced in subjects 53-60 compared to subjects 20-40. No differences were found in blood pressures between the two groups. For the cold face test, bradycardia was more pronounced for older than younger subjects.<br>The gender experiment found that at the beginning of the cold hand test, the responses for men and women were similar. At the end of the test, the change in blood pressure was significantly lower in women. Bradycardia was similar for both in the cold face test but during the 2 minutes following the test, HRs of women remained significantly lower than at the beginning of the test compared to men. Systolic BP returned to initial levels following the cold hand test in males but fell lower for women. | |
| 41 | Lee DT, Toner MM, McArdle WD, Vrabas IS, Pandolf KB | Thermal and metabolic responses to cold-water immersion at knee, hip and shoulder levels. Lee DT, Toner MM, McArdle WD, Vrabas IS, Pandolf KB. J Appl Physiol. 1997, 82(5): 1523-1530 | N = 8 men (mean age 25 yrs and 16% BF) were immersed at rest and during leg cycling exercise (35% $V0_{2\ max}$) in knee, hip and shoulder levels in Tw 15 and 25°C for up to 135 min (limits: Tre 35°C or below or asked to be removed). In this study cycling exercise did not prevent Tre and Tes from falling during immersion @ 15°C in a depth greater than the knee. At shoulder level immersion, in all | 2a |

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| | | | conditions, the combined fractional values for thigh and trunk region contributed btw 59 and 66% of total body heat loss. The arms contributed not more than 25% of heat loss values. This level of exercise did not maintain Tre at baseline levels in shoulder level immersion @ Tw 25°C. | |
| 42 | McArdle WD, Magel JR, Gerley TJ, Toner MM | Thermal adjustement to cold-water exposure in resting men and women. McArdle WD, Magel JR, Gerley TJ, Toner, MM. J Apply Phsiol: Respirat Environ Exercise Physiol 1984. 56(6) 1565-1571 | N = 18 (10 men and 8 women of college age) were immersed to the level of the first thoracic vertebrae for 1 hour @ Tw 20, 24,and 28°C.<br>Fat subjects experienced a proportionately smaller metabolic, thermal and cardiovascular response to cold-water immersion in comparison to leaner counterparts.<br>For men btw 15-18%BF, Tre was maintained at pre-immersion levels during the first 10-20 min of rest at all Tw, and then dropped steadily.<br>For women of average BF (24-27%), Tre deviated only slightly during the first 20 minutes of rest at all Tw. Thereafter Tre steadily decreased with largest reductions @ 24 and 20°C. | 2a |
| 43 | McArdle WD, Toner MM, Magel JR, Spina RJ, and Pandolf KB | Thermal responses of men and women during cold water immersion: influence of exercise intesity. McArdle WD, Toner MM, Magel JR, Spina RJ, and Pandolf KB. Eur J Appl Physiol 1992. 65: 265-270 | N = 16, 8 men (8-18%BF) and 8 women (15-29%) were immersed to the level of the first thoracic vertebrae for 1 hour while performing arm-leg exercise at 3 different $V0_2$ levels. For men these equated to 20, 36 & 49% $VO_{2max}$. For women these equated to 27, 48, and 66% $VO_{2max}$. For women at rest and 27% intensity, Tre declined @ Tw 20 and 28°C. Women maintained a higher Tre @ exercise II and III especially in cold water. At 28°C women had only a slight decrease in Tre with level II exercise and an increase in Tre with level III exercise (66% intensity).<br>Tre for men declined at all three levels of intensity for both 20 and 28°C<br>In 20°C water an exercise intensity of | 2a |

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| | | | about 1.21 l/min-1 and higher was sufficient to maintain Tre at near pre-immersion values. | |
| 44 | McMurray RG, Horvath SM | Thermoregulation in swimmers and runners. McMurray RG, Horvath SM. J Appl Physiol: Respirat Environ Exercise Physiol 1979. 46(6): 1086-1092 | This study was conducted to compare thermoregulatory responses of trained runners (age 20.8±1.1 and %BF 7.4±0.9) and swimmers (age 18.5±0.5 and %BF 9.9±1.2) performing moderate exercise (cycle ergometer) in water @ 20, 25, 30, and 35°C. N = 11, 6 swimmers and 5 runners, immersed to the neck and exercising at 60% (pre-determined) $V0_{2\ max}$ for 30 minutes. Runners and swimmers had similar HR @ any given Tw. HR increased with increased Tw with a significant increase @ 30 and 35°C. Heat production increased in both groups @ Tw 30 and 35°C.<br>During work in 20°C water, runners experienced a negative (-8 ± 2 kcal) heat balance. Swimmers had a positive (13 ± 7) heat storage.<br>Tre for both swimmers and runners increased in Tw above 20°C<br>An optimal temperature for performance can be described as the temperature at which the change in caloric cost is least for a given workload. Optimal Tw for runners was approximately 30°C and for swimmers, approximately 25°C. | 2a |
| 45 | Moore TO, Bernauer EM, Set G, Park YS, Hong SK, Hayashi EM | Effect of immersion at different water temperatures on graded exercise performance in man. Moore To, Bernauer EM, Set G, Park YS, Hong SK, Hayashi EM. Aerosp Med 1970; 41(12): 1404-1408 | This study compared work at three different rates in Ta @ 23-25°C and submerged with SCUBA in 4 feet of water in Tw @ 16, 22, 30°C. N = 8 healthy adult males (mean age 32.2 yrs and %BF 18.0±3.2) underwent 3 work trials (light, moderate and heavy and forced exercise restricted to legs only) in air and three work trials in each of the recorded Tws. (5 min rest, 5 minute work + 3 min rest for light, moderate and heavy with no rest from heavy to forced exercise) approximately 30 min. | 2a<br>2aE |

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| | | | At rest $VO_2$ was generally higher than in air especially at 16 and 22°C. At the highest work level, $VO_2$ was approximately 75% of predicted max Tre did not change significantly in air or in Tw @ 30 and 16°C. At Tw 22°C, one subject (%BF 9.5) experienced a progressive decline in Tre.<br>There was a significantly lower HR at high workloads in water as compared to air. At rest, subjects experienced bradycardia upon initial immersion but HR returned to steady state resting by the end of the trial.<br>This significance of this study is affect of the different modes of exercise on Tre. Leg exercise generally maintained Tre at all workloads in all three temperatures. | |
| 46 | Mougios V, Deligiannis A. | Effect of water temperature on performance, lactate production and heart rate at swimming of maximal and submaximal intensity. Mougios V, Deligiannis A. The Journal of Sports Medicine and Physical Fitness 1993 33(1): 27-22 | N=30 (15 male sprinters and 15 male endurance trained swimmers) Sprinters swam 100M. Endurance swimmers swam for 30 minutes at water temperatures of 20, 26 and 32°C. The subjects characteristics (age 16.4±0.9 and %BF16.0±2.3). Each swimmer did 1 single effort in each temp (5 swimmers in each water temp).<br>All results are compared to a test swim at 26°C: For Sprinters, HR was significantly higher in 32°C and significantly lower in 20°C.<br>For endurance swimmers, HRs rose rapidly in 26 and 32°C and remained fairly constant but continued to rise in 20°C for 20 min and exceeded values in 26°C.<br>There was an observed increase in speed with an increase in water temperature. Based on these findings, we suggest that water temperature is a primary factor in determining the work rate of swimmers. | 2a |

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| 47 | Nadel ER, Holmer I, Bergh U, Astrand PO, Stolwijk JAJ | Energy exchanges in swimming man. Nadel ER, Holmer I, Bergh U, Astrand PO, Stolwijk JAJ. J Appl Physiol. 1974 36(4): 465-471 | N = 3 at rest or swimming breaststroke in three water temperatures (18°, 26° and 33°) at water velocities chosen to elicit 40%, 70% and 100% $VO_2$ max (these were different for each subject) Tb changes after 20 minutes were related to Tw, swimming intensity and body insulation.<br>@ 40% effort internal temperatures fell in 18 and 26°C (inversely related to the degree of insulation and greater in leaner subjects). In 33°C all subjects experienced increased internal temps.<br>@ 70% effort – internal temps increased in 26 and 33°C. Lean subjects had a decrease in Tes at 18°C. All swimmers maintained internal temperatures in all Tw at Maximal effort.<br>For most swimmers, the optimal Tw for maximal swimming performances in sprints would be around 28-30°C, where little heat would be stored and performance would not be impaired. | 2a |
| 48 | Nielsen B, Davies CTM | Temperature regulation during exercise in water and air. Nielsen B, Davies CTM. Acta Physiol Scand. 1976, 98. 500-508 | N=4 subjects swam breaststroke at two different workloads(≈49 and 60%) at a constant pace which they could maintain for 1 hour in water @ 30° or 33°C. The results of these experiments were compared to same subject exercise under the same conditions in air on a bicycle ergometer. The results showed that for a given work load and Ts, Tes and Tre were about 0.04°C lower and conductance values (*K*) were higher in swimming than cycling.<br>Tre increased at both workloads in both temperatures. | 2a |
| 49 | Park YS, Pendergast DR, Rennie DW | Decrease in body insulation with exercise in cool water. Park YS, Pendergast DR, Rennie DW. Undersea Biomed Res 1984; 11(2): 159-168 | This study was an attempt to quantify the relative insulative value of subcutaneous fat vs muscle during prolonged immersion (chin deep) in water 28-32°C (established Tcw for each subject). N = 7 immersed at rest and with 2 levels of arm-leg exercise) | 2a |

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| | | | for 3 hours. At rest Tre dropped exponentially over the 3 hr period. With light exercise (73 kcal•$m^2$•$h^1$), observations were similar to rest. With moderate exercise (120 kcal•$m^2$•$h^1$) there were no significant changes in Tre. | |
| 50 | Pirnay G, Deroanne R, and Petit JM | Influence of water temperature on thermal, circulatory and respiratory responses to muscular work. Pirnay G, Deroanne R, and Petit JM, Europ J Appl Physiol, 1977 ; 37 : 129-136 | N = 5 medical students were immersed, head-out, on a bicycle ergometer in Tw which was modified from 20 to 40°C. They participated in 2 submaximal (efforts approximately 1/3 and 2/3 of $V0_{2\ max}$) and 1 maximal test. Warm water (≥ 30°C) at both submaximal intensities caused hyperthermia. 20°C cold water accelerates heat exchanges between the body and water. Tre was always lower in these conditions but thermal balance was maintained in 20°C with ≈50% intensity.<br>Muscle temp was always higher than Tre, decreasing in cold and increasing in warm water. Maximal $O_2$ consumption varied with Tw. In water @ 20°C, the aerobic capacity was low for all subjects. With an increase in Tw, maximal $O_2$ consumption showed a significant increase. Between 25° and 35°C the rise was moderate and nonsignificant. In very warm (40°C) water, maximum $O_2$ consumption decreased for all subjects.<br>These results indicate that performance is affected water temperature extremes. | 2a |
| 51 | Pretorius T, Bristow GK, Steinman AM, Giesbrecht GG | Thermal effects of whole head submersion in cold water on nonshivering humans. Pretorius T, Bristow GK, Steinman AM, Giesbrecht GG. J Appl Physiol 2006, 101: 699-675 | N = 8 health male subjects studied in 17°C water under 4 conditions: body insulated (dry suit, no hood) with head out or completely submerged, body uninsulated (exposed) with head above or completely submerged.<br>Results analyzed the first 30 minutes of immersion / submersion. Tes decreased significantly after 15 minutes in all conditions. Tes was lower in the head in (submersion) | 2a |

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| | | | condition then for head-out condition from 15 minutes onward. There were no differences btw body insulated, head-in and body exposed, head-out conditions throughout the experiment. The head (7% of the total body surface area) contributed only 10% to the total heat loss. Head submersion increased core cooling rate much more (average of 42%) than it increased total heat loss. | |
| 52 | Pretorius T, Cahill R, Kocay S, and Giesbrecht GG | Shivering heat production and core cooling during head-in and head-out immersion in 17°C Water. Pretorius T, Farrell C, Kocay S, and Giesbrecht GG 2008, Aviat Space Environ Med; 79:495-499 | N=8 male subjects immersed/submersed in Tw @ 17°C under 4 conditions: 1) exposed head-out, 2) exposed head-in, 3) insulated head-out, 4) insulated head-in for a period not longer than 60 minutes (statistics reported on 45 minutes) Tes was unchanged throughout insulated trials – differences in Tes were not significant between insulated head-in and exposed head-out. Total body heat loss was more than twice the amount in the exposed than in the insulated conditions. Head submersion caused a fourfold increase in head heat loss in both exposed and insulated conditions. In the exposed head-in condition, head heat loss accounted for 11% of total cutaneous heat loss (as compared to the head being only 7% of the total body surface area). | 2a |
| 53 | Prisby R, Glickman-Weiss EL, Nelson AG, Caine N | Thermal and metabolic responses of high and low fat women to cold water immersion. Prisby R, Glickman-Weiss EL, Nelson AG, Caine N. Aviat Space Enbiron Med 1999, 70:887-891 | N = 12 females ages 18-35 (6 HF ie; 28-35%BF and 6 LF ie; 15-22%BF) experienced 2 hours of immersion in 17 and 27°C. At 17°C, Tre declined in both groups across time. At minutes 105 and 120 there was a significant difference in Tre between groups. Tsk declined over the first 15 minutes and remained steady for the 120 minutes. Tissue insulation (Ti) increased and Tsk decreased significantly across time | 2a |

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| | | | but there were no significant differences for variables Ti, $V0_2$ and Tsk. | |
| 54 | Pugh LGC, Edholm OG | The physiology of channel swimmers. Pugh LGC, Edholm OG. 1955. The Lancet Oct 8, 761-768 | A three year study of channel swimmers (N=5) ages 21-42, immersion time ranging from 12-20 hours is water @ 15.5°C (60F). Subjects conformed to a certain specific physical type (SA $1.78m^2$ – $2.04m^2$). For thinner subjects, metabolism of swimming was insufficient to prevent hypothermia from developing @ 21.8°C (71.2F). 25°C (77F) was necessary for a stable state. These findings suggest that tolerance of cold water is related to the thickness of subcutaneous fat. | 2a |
| 55 | Rennie DW, Covino BG, Howell BJ, Song SH, Kang BS, and Hong SK | Physical insulation of Korean diving women. Rennie DW, Covino BG, Howell BJ, Song SH, Kang BS, and Hong SK. J Appl Physiol. 1962 17(6): 961-966 | Human cold adaptation was studied by comparing body insulation with 9 Korean diving women, 7 non diving Korean women (12% BF), 7 Korean men(10%BF), 10 American women and 10 American men of various adiposity (16% BF). Subjects were submerged supine for 3 hours with just the face showing in water @ Critical water temperature (between 30 and 34°C).<br>Tcw for Americans with less than 16% BF ≈33-34°C. For more obese Americans it was ≈ 30°C.<br>Korean men (10% BF) Tcw ≈ 33-31°C. For Korean women (12% BF) Tcw≈ 31-30°C and lower.<br>There were no differences in maximal tissue insulation between Korean men and women that could not be accounted for by differences in subcutaneous fat. American tissue insulation is less than the Korean when the two are compared at equal fat thicknesses. | 2a |
| 56 | Robinson S, Somers A | Temperature regulation in swimming. Robinson S, Somers A. J Physiol Paris 1971. 63: 406-409 | Runners and swimmers were compared at the same metabolic rate. N= 6 swimmers age 20-24, swam freestyle for 60 minutes in water @ 21, 29, and | 2a |

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| | | | 33.5°C. The data in this study indicate that optimal water temperature for competitive swimming @ distances requiring up to 20 minutes must be between 21° and 33°C. @ 21°C the average Tre of the slowest swimmers declined. The average Tre of the fastest swimmers rose slightly. Optimal Tw may be nearer 29°C since at that temperature these swimmers central (core) to surface (sk) temperature gradient were adequate for heat conductance. | |
| 57 | Sagawa S, Shiraki K, Yousef MK, and Konda N | Water temperature and intensity of exercise in maintenance of thermal equilibrium. Sagawa S, Shiraki K, Yousef MK, and Konda N. J Appl Physiol 1988, 65(6): 2413-2419 | N= 6 men immersed to the neck for 1 hour in 4 water temperatures<br>Mean Tcw = 31.2±0.5°C<br>Ttn = 34°C<br>Atn = 36°C<br>Mean Btn = Tcw - 2°C or≈ 28.2°C<br>They performed leg exercise at 2, 3, and 4 METs.<br>Resting metabolism was significantly higher in water below Tcw due to shivering. Metabolic rate was the same regardless of Tw. Resting heat loss was greater in the limbs than the trunk. In this study leg exercise caused an increase in Tre compared to rest in all temperatures. LE @ 3-4 METS was effective in maintaining near normal core temperatures in water @ Tcw - 2°C. Two METs was enough to maintain near normal core temperatures @ Tcw. Calculations indicate that a Tw of approximately 25°C may be the lowest Tw in which the average unprotected man can continue exercising without a decrease in Tc (ie: crucial Tw for unprotected exercising man). | 2a |
| 58 | Shimizu T, Kosaka M, Fujishima K | Human thermoregulatory responses during prolonged walking in water @ 25, 30, and 35°C. Shimizu T, Kosaka M, Fujishima K. | N = 8 students(age 18-20 and %BF≈12%), immersed to the xyphoid process performed treadmill walking for 60 minutes @ 50% $V0_{2\ max}$ at three different temperatures. There were no | 2a |

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| | | Euro J App Physiol 1998; 78: 473-478 | significant differences in Tre observed during exercise in water at different temperatures. Tre increased in all temperatures with walking. Tsk of immersed skin was directly determined by Tw. There were identical increases in $V0_2$ at identical intensities which infers that there was no additional demand for thermoregulatory heat production generated by the lowest compared to the higher Tw. | |
| 59 | Sloan REG, Keatinge WR, | Cooling rates of young people swimming in cold water. Sloan REG, Keatinge WR. J Appl Physiol. 1973; 35(3): 371-375 | N= 28 (boys and girls, age 8-19) swam (breaststroke and an occasional length of crawl) for 33 (children under 12 ½) or 40 minutes (older children) in water @ 20°C, waiting on the wall every 2 lengths just long enough to maintain an $O_2$ consumption of 30±1 l/m.<br>Tre fell for all but the fattest swimmers (SCF thickness of 11-18 m X $10^{-2)}$ in 20°C water. The rate of fall in sublingual temperatures decreased with age and as overall fat thickness increased.<br>Boys temp fall rate was faster than girls and for younger children because of lower fat thickness and high surface area to mass ratio. | 2a |
| 60 | Smith RM, Hanna JM | Skinfolds and resting heat loss in cold air and water: temperature equivalence. Smith RM, Hanna JM. J Appl Physiol 1975; 39(1): 93-102 | N = 14 male subjects with a mean skinfold (MSF) of 10.23mm were exposed to 3 hours of air and cold water to determine heat loss (excluding the head). Air temperatures were 25, 20 and 10°C. Water experiments were conducted @ subjects established Tcw (29-31°C). Body heat loss was a linear function of the decrease in Ta in this study. The range of Tcw is mainly a result of the variability in the subjects' subcutaneous fat thickness. Both MSF and Surface area / mass ratio become increasingly more important in cold water. | 2a |
| 61 | Smolander J, Bar-or O, | Thermoregulation during rest and exercise in pre-and | N = 8 boys (mean age 11.8± 0.5yrs) and 11 young adult men (24.7± 4.5 yrs) | 2a |

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| | Korhonen O, Ilmarinen J, | early pubescent boys and young men. Smolander J, Bar-or O, Korhonen O, Ilmarinen J. J Appl Physiol 1992; 72: 1589-1594 | participated in a thermoneutral (21°C) test and a cold stress test (Ta @ 5°C) for 60 minutes at rest and during exercise at 30% $VO_2$ max (pre-determined). Boys had lower BW and significantly greater surface area-to-mass ratio then men. There were no significant differences in skinfold thicknesses or in $VO_2$ max expressed in kg/ml/min.<br>Boys had lower skin temperatures at the extremities and higher $VO_2$ response to the cold than young men. As a result the boys maintained their core temperatures as effectively as the adults. | |
| 62 | Strong LH, Gee Gk, Goldman, RF | Metabolic and vasomotor insulative responses occurring on immersion in cold water. Strong LH, Gee Gk, Goldman, RF J Appl Physiol 1985; 58(3): 964-977 | This study followed changes in core conductance from heat dissipation, via vasodilation, to thermoneutrality and from vasoconstriction to cold induced vasodilation for subjects representing different morphological types.<br>N=20 healthy male volunteers (age17-28 yrs), totally immersed, horizontally, at rest in water @ 28°C and 20°C for 1 hour per week for 10 weeks. Ten subjects were also submerged in water @ 36, 32, and 24°C.<br>Surface heat flow is greatest from the head, thigh, abdomen, large chest muscles.<br>Metabolic responses at 35 and 32°C were essentially the same as pre-emersion value.<br>In general metabolic rates increase as Tw decreases until shivering exhaustion is reached. "There is, however, a marked individual variation at Tw below 32°C<br>Tre fell in Tw below 32°C<br>Tre profiles are more variable among subjects having average BF (12% ≤ BF ≤ 19%) and body wt. (70kg ≤ wt ≤ | 2a |

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| | | | 90kg) | |
| 63 | Tikuisis P, Jacobs I, Moroz D, Vallerand AL, and Martineau L | Comparison of thermoregulatory responses between man and women immersed in cold water. Tikuisis P, Jacobs I, Moroz D, Vallerand AL, and Martineau L. J Appl Physiol 2000, 89: 1403-1411 | N = 11 women and 14 men were immersed to the neck on a cot and lay quietly in Tw @ 18±0.2°C for 90 minutes. The only significant gender difference was the rate of change of Tre. Men and women exhibited similar changes in body cooling and metabolism during cold water immersion @ rest when subject responses were corrected for body fat and surface area/vol. Subjects of both genders with the lowest SA/vol ratio also responded with the lowest ΔTre / Δt. | 2a |
| 64 | Tipton B, Eglin C, Gennser M, Golden F. | Immersion deaths and deterioration in swimming performance in cold water. Tipton B, Eglin C, Gennser M, Golden F. The Lancet. 1999 354: 626-629 | N= 10 swimmers, (age 23-39 and %BF 19.7), swam 90 minutes of breaststroke at Tw 25°, 18°C and 5 swimmers at Tw 10°C.<br>Tre increased with self-paced swimming in 25°C and were similar @ 18°C. Swimming efficiency was similar in 25 and 18°C and remained constant throughout the swim. SE declined in 10°C overtime (decrease in stroke length and increase in stroke rate and an increase in swimming angle). After swimming at 18 and 10°C, grip strength was significantly decreased (11% and 26% respectively). Arms were especially susceptible to cooling with a correlation between swimming failure and upper body skin fold thickness. | 2a |
| 65 | Toner MM, Sawka MN, Foley ME, and Pandolf KB | Effects of body mass and morphology on thermal responses in water. Toner MM, Sawka MN, Foley ME, and Pandolf KB. J Appl Physiol 1986, 521-525 | N = 10 (5 LM and 5 SM) with similar BF and SF thicknesses were immersed in a seated position to the neck at rest and during exercise (M approximately 550 w) in Tw @ 26°C for 1 hour. At rest Tre and Tsk were lower at hour in both groups then at 5 and 30 minutes. There was a significant relationship between skinfolds and Tre during rest | 2a |

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| | | | in cold water. Ti values were higher for LM compared to SM both prior to and during immersion. There were no significant differences between groups with exercise immersion. | |
| 66 | Toner MM, Sawka MN, and Pandolf KB | Thermal responses during arm and leg and combined arm-leg exercise in water. Toner MM, Sawka MN, and Pandolf KB. J Appl Physiol: Respirat Environ Exercise Physiol, 1984. 56(5): 1355-1360. | Thermal and metabolic responses were examined during exposure in stirred water @ 20, 26, and 33°C. N = 8 males (age 22.4 ±3.6 and %BF 13.4 ±5.7) were immersed to the neck and exercised either arms only (A), legs only (L) or arm-leg combined (AL) for 45 minutes. Each subject completed each specific type exercise at both high (≈60%) and low (≈40%) intensities. At 40% intensity M was significantly higher in 20 and 26°C during A compared with 33°C and higher only in 20°C for L and AL exercise. In 20°C Tre values declined steadily for all types of exercise at 40% intensity. In 26°C Tre declined with 40% intensity for A and AL exercise but remained steady with L. During 60% intensity exercise in 26°C and 33°C, Tre steadily increased for L and AL. | 2a |
| 67 | USA Swimming | 2010 USA Swimming Rules and Regulations. USA Swimming 2010 | Rule 103.6 – water temperature between 25-28 degrees Celsius (77-82.4 degrees Fahrenheit) shall be maintained for competition. | 5 |
| 68 | Veicsteinas A, Ferretti G, and Rennie DW | Superficial shell insulation in resting and exercising men in cold water. Veicsteinas A, Ferretti G, and Rennie DW. J Appl Physiol: Respirat Environ Exercise Physiol 1982 ; 52(3): 1557-1564 | N = 9 male subjects (BF ranging between 8.8 and 27.2%) immersed, head out, and rested for 3 hours in Tcw (28-33°C) to study tissue insulation. Immersion at rest in Tcw created an initial large change in tissue insulation which, after 20 minutes reach and remained constant throughout. Vasodilation occurred at Tw 32 -33°C. The results indicate that insulation provided by unprofused skin and subcutaneous fat accounts for only 10-15% of Ti during rest in Tcw. The remaining is most likely poorly | 2a |

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| | | | profused muscle.<br>Protocol 2 included mild exercise with immersion. Tre increased ≈1°C over two hours of immersion | |
| 69 | Wade CE, Dacanay SD, and Smith RM | Regional heat loss in resting man during immersion in 25.2°C water. Wade CE, Dacanay SD, and Smith RM. Aviat space Environ Med 1979; 50(6):590-593 | N = 5 male subjects (age 19-33 and %BF ranging from 9.22 to 20.17) were immersed at rest, lying on a cot in Tw @ 25.2°C for 30 minutes. Regional heat flows were greatest in the neck, head, and upper torso and total regional heat loss was greatest from the torso. Heat flow from the neck, head, and torso was significantly correlated with skinfold thickness. No significant correlation was noted in the extremities. Subcutaneous fat is the most important factor in determination of total body heat loss. The torso, head and neck account for 63% of the heat loss in 25.2°C water. | 2a |
| 70 | Wade CE, Veghte JH | Thermographic evaluation of the relative heat loss by area in man after swimming. Wade CE, Veghte JH. Aviat Space Enviorn Med 1977; 48(1): 16-18 | N=4 competitive swimmers ages 16-21 and % BF ranging from 8.3-27.2) underwent a 5 minute non swimming immersion and a 500m freestyle swim at training pace (60-75%) in Tw @ 23.5°C. Subjects were scanned for surface temperature prior to immersion and after each of the aforementioned conditions. Skinfold thickness was found to correlate with the change in Tsk. Radiograms of the subjects after immersion showed the warmer areas were the chest, groin, lower abdomen, and lower neck.<br>After swimming, the warmer areas were active muscle masses (trapezius, deltoids, triceps, biceps brachi, and pertorals). The legs were cooler. | 2a |
| 71 | Wagner, JA, Horvath SM | Influences of age and gender on human thermoregulatory responses to cold exposures. Wagner, JA, Horvath SM. J Appl Physiol 1985; 58(1): | N = 10 men and 10 women ages 20-30 and 10 men and 7 women ages 51-72 were exposed (with minimal clothing) for 2 hours to Ta @ 28, 20,15 and 10°C while resting in a semi-reclining | 2a<br>2aE |

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| | | 180-186. | position. Results suggest that older men may be more susceptible to cold ambient than younger people since they did not prevent a drop in Tre and had a lower initial Tre. Older women, by virtue of higher %BF and rapid increase in metabolic rate did quite well.<br>Changes in Tre and Tsk were greatly dependent on the amount and distribution of BF. | |
| 72 | Wagner, JA, Horvath SM | Cardiovascular reactions to cold exposures differ with age and gender. Wagner, JA, Horvath SM. J Appl Physiol 1985; 58(1): 187-192 | N = 10 men and 10 women ages 20-30 and 10 men and 7 women ages 51-72 were exposed (with minimal clothing) for 2 hours to Ta @ 28, 20,15 and 10°C while resting in a semi-reclining position. Heart rates ($f_c$) decreased significantly over time during cold exposure in men but not in women. Regardless of age, men had higher stroke volume (Qs) during the last hour in all three colder environments when compared to 28°C. Women did not. During 28°C exposure, men had significantly higher total arm blood flows than women.<br>Younger subjects always had significantly higher Qs than older subjects. There were no significant differences in blood pressures between men and women but older subjects had higher blood pressures than younger subjects did. Older subjects had higher forearm blood flows than younger subjects for the first hour of exposure in 28°C. The results of this study indicate that cardiovascular adjustments to moderate cold exposure differ with both age and gender. | 2a<br>2aE |
| 73 | Wakabyashi H, Kaneda K, Okura M, and Nomra T | Insulation and body temperature of prepubescent children wearing a thermal swimsuit during moderate-intensity water exercise. Wakabyashi H, Kaneda K, | N = 9 prepubescent children ages 11±0.7 years ( %BF, 15.1±4.9%) were immersed in Tw @ 23°C up to their chest and pedaled on a cycle ergometer for 30 minutes wearing a TSS or a normal swim suit (NSS). The TSS | 2a<br>2aE |

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| | | Okura M, and Nomra T. J Physiol Anthropol, 2007:26(2): 179-183 | made of 1.5mm thick neoprene covered the thighs, trunk, upper arms and neck. Submaximal exercise intensity was based on a pre-test measured in an elementary swimming class (HR = 130-140 bpm).<br>Tre was maintained slightly higher using TSS than NSS. Total insulation was higher with TSS. Tissue insulation was related to %BF in the NSS condition and was lower in the lowest fat subjects. Prepubescent children with low body fat can maintain Tre at the same level as obese children by wearing a TSS. | |
| 74 | Wakabyashi H, Hanai A, Yokoyama S, and Nomra T | Thermal insulation and body temperature wearing a thermalswim suit during water immersion. Wakabyashi H, Hanai A, Yokoyama S, and Nomra T. J Physiol Anthropol, 2006:25(5): 331-338. | This study compared healthy men wearing either a normal swim suit or a thermal swim suit immersed in water @ 26 and 29°C for 60 minutes.<br>Tes was higher in both temperatures for the thermal suit than the normal swim suit. A thermal swim suit can increase total insulation and reduce heat loss from the skin. | 2a<br>2aE |
| 75 | Weihl AC, Langworthy HC, Manalaysay AR, Layton RP | Metabolic responses of resting man immersed in 25.5°C and 33°C water Aviat Space Environ Med. 1981 52(2) 88-91 | N= 16 unprotected Navy divers *(age and %BF NA)* underwent total immersion with a mask, sitting at 3M in Tw 25.5° and 33°C. There were 3 total submersions of 14 minutes each. Subjects were raised just long enough to obtain a venous sample.<br>Tre declined in all subjects at 25.5°C. Exposure to 25°C resulted in uncontrollable shivering by the 42$^{nd}$ minutes. In 33°C there was no significant difference in Tre. | 2a |

| **Level of Evidence** | **Definitions (See manuscript for full details)** |
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| **Level 1a** | Population based studies, randomized prospective studies or meta-analyses of multiple studies with substantial effects |
| **Level 1b** | Large non-population based epidemiological studies or randomized prospective studies with smaller or less significant effects |
| **Level 2a** | Prospective, controlled, non-randomized, cohort or case-control studies |
| **Level 2b** | Historic, non-randomized, cohort or case-control studies |
| **Level 2c** | Case series: convenience sample epidemiological studies |
| **Level 3a** | Large observational studies |
| **Level 3b** | Smaller observational studies |
| **Level 4** | Animal studies or mechanical model studies |
| **Level 5** | Peer-reviewed, state of the art articles, review articles, organizational statements or guidelines, editorials, or consensus statements |
| **Level 6** | Non-peer reviewed published opinions, such as textbook statements, official organizational publications, guidelines and policy statements which are not peer reviewed and consensus statements |
| **Level 7** | Rational conjecture (common sense); common practices accepted before evidence-based guidelines |
| **Level 1-6E** | Extrapolations from existing data collected for other purposes, theoretical analyses which is on-point with question being asked. Modifier E applied because extrapolated but ranked based on type of study. |

**Table**

| LOE | Ref # | Head in | Head out | Age range | Immersion time | Exercise intensity | % BF | Temp range | Temp @ΔTre |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 9 | | To the neck | | 60 min | MR + 60kcal | SFT<br>Lean 2.8±0.2<br>Normal 4.5±0.2<br>Obese 7.7±.3 | 15,20, 25, 30, 35°C | ↓with Tw less than 30°C regardless of rest or exercise<br>Gradual ↓in Tre after the first 20 min |
| 2 | 11 | swimming | | 18-29<br>Mean 21.13 | 20 min | Submax | 4.6 – 10.4<br>Mean 7.7% | 17.4, 26.8, 33.1 | ↑Tre in all temperatures<br>↓Tre during recovery @ 17.4 Tre was lower than control |
| 2 | 12 | | Immersed to the chin<br>Semi-recumbent | 26 | 60 min | NA | 15.5±8.1%<br>SCF 5.4±1.4 | 24, 26, 28, 30, 32, 34, 36, 37°C | In Tw ≤ 35°C, Tc were below control values at 60 min of immersion.<br>↑Tre in 24, 26, 28°C over the first 10-20 minutes.<br>↑$V0_2$ occurred in 30°C @ 40 minutes or less.<br>For 60 minutes Tw would have to be 32°C to prevent shivering<br>↑Tre @ 36 & 37°C |
| 2<br>2E<br>TA 27±1.6°C<br>Humidity 55±8 % | 13 | | Head out nearly horizontal | 27±5.8 | 60 minutes | Submax light work load | 14% BF | 24, 26, 28, 31, 31, 32°C | ↑Tre @ 28-32°C w/high work loads<br>↓T-ear @ Tw <32°C with low workload<br>@ 60 min increment in temp same as resting<br>Temp to prevent ΔTre for light workload is 34°C. For heavy workload, 29°C |

| **LOE** | **Ref #** | **Head in** | **Head out** | **Age range** | **Immersion time** | **Exercise intensity** | **% BF** | **Temp range** | **Temp @ΔTre** |
|---|---|---|---|---|---|---|---|---|---|
| 2<br><br>Ta 25°C, RH 65% | 20 | Swim Breast stroke Constant speed | | 19.8± 0.9 years | 120 min | 50±5%max @23°C<br>43±6% @ 28°C<br>42±4% @ 33°C | 13.2±3.4% | 23, 28, 33°C | Tre steadily declined and was significant after 20 minutes @ 23°C and 28°C<br>No change at 33°C |
| | 21 | Swim breast stroke | | 23-41 years | 60 min | 65% max | NA | 21, 27, 33°C | ↓Tre @ 21°C<br>↑significantly @ 33<br>And to a smaller extent in 27°C |
| | 23 | | Sitting<br>Ist thoracic vertebrae | 18-30<br>40-55 | 40 min or when Tes ↓ to 36.5°C | NA | 10.9±2.9%<br>13.7±8.4% | 20°C | Tes ↓in both age groups at 20°C at rest |
| | 24 | | Ist thoracic vertebrae | 20-35 | 90 min | NA | LF = 9-12%<br>HF = 18-22% | 18-22-26°C | Tre declined as a function of time and were similar for all subjects at each time point over the 90 minutes. |
| | 25 | | Sitting<br>Ist thoracic vertebrae | NA | 120 min | NA | 14.5±4.1% (LM)<br>16.5±3.5% (SM) | 18°C | Tre declined for all subjects as a function of time |
| | 30 | Swimmin g<br>Vs running | | 14-29 mean 21.4± 7.3 | 20 min | 50%max | 8.2±3.2% | 18,26, 34°C | ↑Tes in 26 & 34 with max<br>↑Tes in 26 & 34 with submax<br>The leanest subject (3.8%BF) could not sustain Tes w/submax swimming in 26 or 18°C<br>Subject with 6.2% BF maintained Tes in 26°C |

| **LOE** | **Ref #** | **Head in** | **Head out** | **Age range** | **Immersion time** | **Exercise intensity** | **% BF** | **Temp range** | **Temp @ΔTre** |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 31 | Swim breast stroke | **NA** | | 60 min | 65% max | **NA** | 21, 27, 33°C | ↑Tre and Tes @ 27 & 33°C<br>↓Tre @ 21°C |
| 2<br>2E | 32 | | Immersed to the neck | 21-32<br>Mean 26.8 | 30 min | 60% max cycling | 14.8± 5.6% | 21, 25, 29°C | ↑Tre@ 29°C<br>Similar @ 25°C<br>↓@21°C |
| 2<br>2E<br>Ta 30°C<br>RH 60% | 33 | | To the neck water circulated | 23-36 | 120 min | NA | 15.3± 1.2% | | Tcw 32± 0.4°C<br>Tes↓ at a faster rate in the first hour than in the second |
| 2<br>2E<br>Ta 25°C | 36 | | To the shoulders | 19-26 | 20 min | Rowing ergometer A standard rate? | NA | 5, 15, 25, 35, 37°C | ↑Tre @35°C<br>Slight ↓with work in Tw<25°C |
| 2<br>2E<br>Ta 24-26°C | 38 | | To the neck | 18-22<br>22-31 | 60 min | NA | 21-24% BF<br>29-41% BF | 20°C | Tre for obese rose over the 1st 15 min and then slowly dropped<br>Tre for Lean ↓1.4°C compared to .4°C for obese |
| 2<br>2E | 41 | | Shoulder immersion | 25 | Up to 135 min | 35% max | 16% | 15,25, 35°C | ↓Tre@ 25°C |
| 2<br>2E | 42 | | 1st thoracic vertebrae | 19-29 | 60 min | NA | Men 15-18%<br>Women 24-27% | 20, 24, 28°C | Men 15-18%BF -Tre remained constant for 10-20 min<br>For women 24-27%, Tre remained constant for 20 min then declined in all Tws |

| LOE | Ref # | Head in | Head out | Age range | Immersion time | Exercise intensity | % BF | Temp range | Temp @ΔTre |
|---|---|---|---|---|---|---|---|---|---|
| 2<br>2E | 43 | | 1st thoracic vertebrae | 19-29 | 60 min | Arm/leg ergometer<br><br>20,36,49 % for men<br><br>27, 48 and 66% for women | 8-18%<br><br>15-29% | 20, 28°C | For women Tre ↓ at rest and Level I intensity @ 28°C<br>Tre ↑ slightly for both level II and III (48-66% max)<br>In males Tre↓ in 20°C at all exercise intensities<br>Tre↓in 28°C for level I and II exercise but ↑with 49% intensity<br>For women Tre |
| 2<br>2E | 44 | | To the neck | 18-22 | 30 min | 60% max | Runners 7.4±0.9%<br>Swimmers 9.9±1.2% | 20,25,30, 35°C | Runners ↓Tre in 20°C<br>Swimmers ↑Tre in 20°C<br>(non significant)<br>Tre ↑in all Tw above 20°C |
| 2<br>2E | 45 | Submerge d with SCUBA | | 23-42 (32.2) | 5 min rest, 5 min work followed by 3 min rest<br>At each work load.<br>≈30 min | Light<br>Moderate<br><br>Heavy (75% max) | 18.0±2.3 | 16, 22, 30°C | Tre was maintained with all workloads at all temperatures during the 5 minute exercise bouts |
| 2 | 47 | Swam breast stroke | | 24-26 | 20 min | 40, 70, 100% max | 12.4<br>8.7<br>7.4 | 18, 26, 33°C | @40% ↓Tre in 18 & 26°C<br>@ 70%↓Tre with 2 leanest subjects in 18°C<br>@ 70% ↑Tre in 26 & 33°C |
| 2 | 48 | Swam breast stroke | 23-32 | | 60 min | Moderate ≈ 49%<br>≈60% | SFT = 8.3-9.4 | 30 & 33°C | Tre ↑at both workloads in both temperatures |

| LOE | Ref # | Head in | Head out | Age range | Immersion time | Exercise intensity | % BF | Temp range | Temp @ ΔTre |
|---|---|---|---|---|---|---|---|---|---|
| 2<br>2E | 50 | | Head out | Medi cal stude nts | 15 min | Bicycle ergometer 33%, 66%, 100% | NA | 20-40°C | Hyperthermia in Tw ≥ 30°C at ≈50% intensity<br>At ≈50% intensity, thermal balance was maintained (+) in 20°C |
| 2 | 56 | Swam freestyle | | 20-24 | 60 min | Various | NA | 21, 29, 33.5°C | Tre of the slowest swimmers ↓in 21°C<br>Tre of fastest swimmers ↑ @ 21°C<br>Tre↑ in 29°C<br>Swimmers became distressed in 33.5°C |
| 2<br>2E<br>Ta 25°C<br>RH 56% | 57 | | To the neck<br>In stirred water | 24-50<br>Mean 43±4.1 | 60 min | LE<br>20, 30 and 40% max | 18-23<br>Mean 19.9±1.2% | 31.2, 28.8, 34, 36°C | Tre ↑at all temperatures with all workloads<br>20% intensity was enough to maintain Thermal balance in Btn |
| 2<br>2E | 58 | | To the xyphoid | 18-20 | 60 min | Walking 50% max | 7.0-15.0<br>Mean 11.1±2.5% | 25, 30, 35°C | Tre ↑over the 60 min at all temperatures |
| 2 | 59 | Swam breast stroke and some freestyle | | 8-20 | 33 min<br>40 min | Easy to moderate 30±1 l/m | SFT<br>Between 5.8 and 19.2 m X $10^{-2}$ | 20°C | Tre ↓in all cases<br>Non significant decreases with individuals whose SFT was btw 11-18 |
| 2<br>Ta 23-24°C | 62 | Totally immersed<br>In still water | | 17-28 | 60 min | NA | 23%<br>11-15%<br>7-9% | 20, 24, 28, 32, 36°C | Tre between groups at 20°C differed by as much as 1°C<br>Tre the same @ 32 & 35°C and ↓ in Tw below 32°C except for the heaviest subjects |

| LOE | Ref # | Head in | Head out | Age range | Immersion time | Exercise intensity | % BF | Temp range | Temp @ΔTre |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 64 | Swimming breast stroke | | 23-39 Mean 30 | 90 min | Self paced | 10.6-26.8% Mean 19.7% | 18 & 25°C | Tre ↑ @25°C Tre nearly the same @ 18°C |
| 2 2E | 66 | | To the neck | 22.4± 3.6 | 45 min | A, AL, L ≈ 40% & ≈60% | 13.4±5.7% | 20, 26, 33°C | ↓Tre in 20°C low intensity exercise ↓ Tre in 26°C with low intensity≈ 40% exercise except L ↑Tre in 26°C & 33°C for high intensity≈ 60% AL and L |
| 2 | 74 | Total immersion Sitting @ 3M | | Navy divers | 45 min | NA | NA | 25.5°C and 33°C | Tre ↓in all subjects @ 25.5°C Uncontrollable shivering at minute 42 ↓in Tre @ 33°C non-significant |