Heat Production and Dissipation During Exercise

By Ken Hutchins
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This subject extends into many practices and beliefs in the fitness community. They include exercise environmental controls as well as exercise apparel.

As Arthur Jones explained in one of the early *Nautilus® Bulletins (Circa 1970)*, heat from an animal is produced in direct proportion to its mass, while its heat dissipation occurs in direct proportion to its *surface area per mass.*

For example: a shrew is a tiny mammal that produces a relatively small amount of body heat, but for whatever that heat production value is, it is dissipated very quickly, because a shrew has a tremendous surface area relative to its mass.

A shrew, therefore, lives a constant struggle to stay warm, driving it to eat constantly merely to obtain the necessary energy foodstuffs to maintain body heat. This is why a shrew does not usually thrive in a frigid part of the world. A shrew faces a heat *retention* challenge.

An elephant, on the other hand, possesses the exact opposite problem. Its mass is relatively large, thus producing a tremendous amount of heat, but because of its size, its *surface area per mass* is very small. This arrangement poses a heat dissipation challenge to the elephant. It is in constant danger of overheating and thrives only in environments where it can remain cool. An elephant faces a heat *dissipation* challenge.

Of course, there are exceptional environments for each of these mammals. They, like us, have developed both physical and behavioral means to deal with their limitations. By living underground and amidst rotting vegetation, as well as by staying very active, shrews can produce and conserve some of their body heat even though living in a temperate environment.

By evolving large membranous ears used as heat radiators and by staying at higher elevations, elephants can survive in temperate climates. Note that Indian elephants are both smaller and with relatively smaller ears, perhaps indicating a heat dissipation problem slightly less severe.

Put a large block of ice in a bathtub of water at 70 degrees Fahrenheit and note that it takes hours for it to melt. But chop the same block of ice into small chips and note that all the ice melts in a fraction of the time. In the first instance the ice possesses a smaller *surface area per mass,* while in the second instance the ice possesses a larger *surface area per mass.* The mass remains the same in both cases.

Note that there are, past and present, larger animals than elephants. Whales are warm-blooded mammals that produce large quantities of heat. Being confined to the water is both an advantage as well as a disadvantage, since most of their heat is dissipated through conduction directly to the surrounding water. And if the water possesses more heat, the whale will *acquire* rather than *dissipate* heat, thus leading to death if this process is prolonged. Luckily the whale can usually find water in a climate cooler than its body temperature, or if needed, submerge to deeper, cooler water at almost any time or location in the ocean.

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Dinosaurs were once thought to be cold-blooded, stupid, sluggish creatures living in a hot climate. It is now believed by many paleontologists that dinosaurs were, instead, warm-blooded animals with high metabolisms. If so, this suggests that their climate of choice would have been cool, even cold.

Other Factors: Relative Fatness and Muscularity Did you ever notice that many women in a large office constantly complain of being uncomfortably cool? Yet most men do not complain. Why? Because, although the women have far more insulating body fat to retain their heat, they have considerably less muscle mass and therefore their metabolisms are significantly lower. The muscles are the furnaces of the body and have a marked effect on heat production. Note that even the women who are as large as the men due to their fatness—sometimes exceeding 50% bodyfat—still remain cold in the same environment even though their *surface area per mass* may compare to that of a man.

The War of the Thermostat I suppose this, in part, explains why the typical business office has a phony thermostat. You see, the office manager and the building engineer often receive endless complaints that the temperature is too high or too low. The women complain of being too cold, and if they are accommodated, the men will complain of being too hot. To solve this, a dummy thermostat is sometimes installed for the staff to operate. Thus the complainers are apparently appeased.

Heat Production in Exercise As in other mammals, humans produce more heat as they increase the intensity of muscular activity, such as that which takes place during exercise. The quantity of heat is roughly proportional to their size, strength, will and ability to work intensely.

As body heat increases, the viscosity of the serous membranes between the muscle sheaths decreases, hence permitting better performance, at least up to a point. Beyond a certain permissible threshold, heat becomes a threat to performance. As the brain overheats, thinking becomes fuzzy and the will degenerates, thus compromising optimal intensity of effort. Beyond this, excessive heat becomes a threat to life and classic heat illness sets in. This can be a critical situation for obese and/or elderly subjects. And specifically, heat is also a critical factor for certain medical conditions, such as multiple sclerosis.

The dissipation of heat is multi-factorial. The ideal combination of factors includes:

- low ambient temperature (within reason)
- low ambient humidity
- ample ventilation.

These three factors held ideal, a subject who possesses minimum insulating body fat and who is hydrated enough to produce copious sweat excretion onto the skin surface is the person who possesses the best chance for maximizing performance.

The Body's Evaporative System Fundamentally, the human body functions to cool itself as an evaporative air conditioner, although several other systems are simultaneously operating to help with this same heat dissipation challenge.

Sweat glands reside in the skin all over the body (except the glans penis, the margins of the lips, and the nail beds). Increased temperature stimulates them to excrete sweat which is mostly water. This moisture, in the presence of dry air, evaporates. This evaporation is endothermic, which

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means that heat is *acquired* (in this case to the water vapor) during the process. Thus the heat is *given up* by the body.

The mechanics are as follows: The body conducts heat to the water. The water then leaves the inside of the body carrying the heat with it to the surface of the body. Then in a low-humidity atmosphere, the water evaporates, using the heat of the sweat as well as drawing more heat from the body to accomplish the evaporative process.

The same process works with the weather. Water vapor is produced off the surface of the earth upon being heated by the sun. This heated as well as expanded vapor rises to cooler altitudes where it relinquishes its heat (exothermic) and condenses to form clouds, condensing yet more to form rain.

In a sense the earth sweats just as we humans do.

Evaporative Air Conditioning I was first introduced to evaporative air conditioning when stationed with the Air Force in West Texas. There, I lived in a house with a simple evaporative unit. A water hose supplied a constant drip of water that evenly misted down through metal fins like that found in a car's radiator. A blower powered by an electric motor blew a constant stream of hot, dry air. As the air passed through the mist, the water mist became vaporized using the heat from the warm air. The now cooler air was then blown into the house. This evaporative system worked very well.

The evaporative AC works so well that I am amazed that it is not more commonly used in arid climates. Admittedly, it is far more primitive than refrigerated air, the more common form of cooling today. And it has a far more limited application since it does not work in humid environments. And this brings us back to the human body.

As already stated, the body cools itself through other processes in addition to sweat evaporation. As temperature rises, especially during labored breathing, large quantities of warm water vapor are expelled through ventilation. Also, the mere loss of water through sweating, ventilation, and urination/defecation removes heat in and of itself; i.e., without evaporation of water on the skin.

This last situation can lead to serious problems, because in a humid environment the body's evaporative air conditioning system fails. This occurs because the ambient atmosphere is already water saturated, and the evaporation process has nowhere to go. And this forces the body to rely on the other, more limited means to cool itself. These might be by radiation and/or by conduction. (Remember that the three kinds of heat transfer are conduction, convection, and radiation. Also realize that it is not unusual for more than one kind of transfer to occur simultaneously.) And this possible solution is hampered if the ambient atmosphere is also hot, thus preventing meaningful heat conduction and radiation by the body to the local environment.

To help read the body's status report, so to speak, on its cooling efficiency, the following possibilities are associated:

- *If, during intense exercise, the body sweats profusely, but the sweat collects on the surface of the skin and does not evaporate.* In this case the subject is soaking wet with his own sweat. Even his clothes are wet. Although fitness lore would have you believe that such "sweating is healthful," this situation is actually a potentially harmful failure of the

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body's evaporative process. This surface wetness can also trap heat and slow direct radiation and conduction of heat away from the body. Note that fern growers in Florida actually spray water on their crops when the temperature drops *to prevent freezing*.

One sometimes also hears lore that, "Sweating removes impurities (or toxins) from the body." This is silly. Do you ever consider that your perspiration is full of toxins or poisons? In that case we should be equally repulsed by sweat as we are by urine or feces.

- *If the surface of the skin is dry*. Here, we have a mixture of possibilities. If cool and dry, I would suppose that the evaporative system is working perfectly and that the evaporative process is staying ahead of the radiation and conduction processes.

  Realize that "sweating" does not necessarily mean becoming *wet with sweat.*

- *If the surface of the skin is warm and dry.* In this case, I might become concerned. This concern depends on the length of the workout, the leanness of the subject and the location of heat on the skin. Although dry skin might suggest perfect functioning of the evaporative process, dry skin might also suggest that the subject is poorly hydrated, thus in evaporative failure—from the front end, so to speak—and in serious danger of heat illness.

I would not be overly concerned if the skin were dry and warm only in the neck and head regions. This is an area through which much heat is dissipated—so much that it is closely monitored by anesthesiologists during surgery to protect brain function.

Also, I am yet less concerned when the SuperSlow® workout requires only 20 minutes. A minimum of problems are likely to occur with such short exposure.

Knowing the foregoing information, we can plan the ideal atmospheric controls for a SuperSlow workout.

- The first recommendation is to keep the room temperature about 68 degrees Fahrenheit and to maintain this with refrigerated air. Refrigerated air, by its very process, removes water vapor from the air as it cools. This type of system keeps our studio at about 50% humidity, although outside humidity in Florida is commonly above 80%.

  Cooler temperatures for the workout area have been suggested and applied; however, I do not believe that much cooler than 68 is necessary with adequate ventilation. Also, going lower makes staff unable to function and electricity cost to soar disproportionately.

- The second recommendation is to keep the subject well ventilated. In other words, use fans to constantly move the air onto the subject. The overall space of the workout may be relatively dry, although the subject is working in a self-created cloud of invisible water vapor and heat that chokes his evaporative efficiency to a greater or lesser degree. This cloud must be pushed away and dispersed by constant ventilation for the subject to remain as cool as possible. This constant flow of cool air also greatly affects the efficiency of direct radiation of heat through the surface of the skin. Ventilation works to accomplish convection.

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- The third recommendation regards workout apparel. Clothing should be close-fitting, not baggy or loose, but not tight as to be constrictive.

  The kind of fabric is also important. Avoid popular so-called "warm-up suits" of any kind, particularly those made of synthetic and water repellent fabrics that hold in heat and moisture.

  Warm-ups and sweats are not only bad for heat dissipation, but also are often baggy. Baggy apparel tends to hang up on equipment parts and make constraints such as seat belts difficult to properly tighten.

  Another concern is visibility. The instructor needs the ability to observe the joints to note alignment and discrepancies. Excessive coverage, especially with baggy designs, obscures the landmarks.

  Avoid long leggings, long sleeves and tight closures, such as turtlenecks that tend to trap heat.

Temperature Effects on Exercise Several times I have observed dramatic changes in exercise performance due to ambient temperature. In a facility where I worked for several years, the temperature was controlled by a central computer in our four-story office building. Twice this computer malfunctioned and kept the gym temperature in the middle 50s Fahrenheit. Among those subjects I trained who had long before plateaued their performances on six to eight exercises, almost all improved performance on every exercise. Of course, this occurred amidst great difficulty dissuading these subjects from overdressing for comfort reasons. They were all surprised when shown their records of their respective workouts.

Another observation—a reverse association—was to note the temperature and humidity change in a confined gym before and immediately after intense workouts of one or two strong, large male subjects. During these workouts, I have seen the temperature rise 5 degrees and the humidity rise from 50 to 90%. Of course, the air conditioning system could bring these values back into line within a few minutes.

Avoid Headgear Apparel concerns also include the use of headgear like caps and sweat bands. As heat dissipation is dramatically greater through the nape and scalp, it does not make much sense to cover or constrict these areas. For these same reasons turtleneck tops, scarves, wigs and high collars are to be avoided.

Note that in the past, both men and women wore nightcaps to bed in order to retain body heat that might be lost through the scalp.

Hunting Alligators At this juncture, I must interject some discussion regarding my experience with headaches and headbands. As many readers already realize, I am very protective with subjects against the possibility of exercise-induced headaches (E.I.H.). With this also in mind, I strongly dissuade them from wearing headgear. Why?

Answer: As a teenager during the warmer seasons, I hunted and captured alligators and raccoons several nights per season. With the local game warden's knowledge and approval—it was illegal

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to catch alligators in Texas during those years—we caught smaller alligators and nurtured them in our private lake before repopulating the lakes in the surrounding Conroe, Texas area.

Each night we hunted, we struck out no sooner than 10 p.m.—usually 11 p.m.—and returned home before daybreak. I did not consistently bring home alligators. I did consistently arrive home with a headache. I guess I will never know for sure, but I blamed these headaches on the headband that supported my headlight. I constantly tried new headlights to find progressively more comfortable headbands. It seemed no matter how perfectly comfortable the headband, several hours of wearing it caused a headache.

I admit that eye strain and staying awake all night contributed to this problem, but I rarely acquired the headache while driving back and forth to school in Lubbock, often an all-night drive into constantly changing darkness to bright truckers' headlights.

I also admit that headlights are often used by coalminers, although they are usually mounted on the front of the hard hats—which of course involve a headband type support inside them.

Although I am skeptical of the headband-headache association, I remain conservatively cautious with such apparel during workouts as I greatly dislike witnessing clients sustaining EIH.

Other Recommendations

- Subjects who bundle up for a workout can't be seriously interested in obtaining the best possible workout. That point in the workout where they normally become overheated and lose will and motivation will come sooner in the sequence of exercises because they dress warmly. <u>They should not peel off their outer sweater as they warm up, but should instead start the workout pre-cooled, almost to the point of discomfort.</u>

  As a threatening threshold of temperature is reached, the body starts processes to cool itself. In general, it is important to start the processes well before a damaging and critical temperature is reached—in the case of the workout—before heat rises to thwart the best exercise effect.

- Subjects must not work out in jeans. Jeans are hot, inflexible and often have metal rivets that can tear upholstery. One torn pad can cost $50–$200, plus down time. This damage is also a risk with warm-ups that have zippers in unusual locations.

- Subjects sometimes complain that their hands and feet are cold. Realize that your core temperature can be overheating simultaneous with your hands being frostbitten. Many people die shoveling snow. I suspect that part of this is due to exertion—including overheating of the trunk. Note that this life-threatening heat is produced as they are struggling to protect their hands from frostbite. The shoveler responds to the cold on his hands, feet, nose and arms by overheating the core. Also, his body responds to the whole mass.

- If tights or leggings are used, those that are cut to just above the knee are best. This exposes the knees for observation, yet covers the thighs to prevent the upholstery from grabbing the skin. Ensure that they are a snug fit but not so tight as to constrict.

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- When informing subjects that their sleeves are too long for efficient exercise, they invariably and instantly respond by rolling up their sleeves. This, of course, makes the situation worse, as the arms are then constricted and ventilation is blocked.

Four Reasons to Dress Briefly
And Snugly
During Exercise

- To Dissipate Heat
- To Enable Your Instructor to Visualize Alignment
- To Enable Your Instructor to Detect On/Offing
- To Minimize Hang-ups on the Equipment Leading to Injuries

- Sometimes, subjects complain that the cold air in the gym gives them a sore throat. Note that this is not an actual infection-type sore throat. Their throat is merely dried and irritated due to the initial heavy ventilation of dry air produced by the refrigeration process—a kind of mild abrasion. It will go away after the first workout in most cases.

- Dissuade subjects from exercising when a sore throat or fever is an indication of an infection. To deal with an infection, the body must fend off an elevated temperature which is exacerbated by increased heat production due to the workout. Once on the mend, a workout of a moderate intensity may serve to hasten recovery, but a hard one may cause a relapse. Such relapse can even be life-threatening. I have personal experience with this regarding hepatitis recovery.

- It is my personal theory—stated to several physicians for criticism and not yet challenged—that chills due to a state of fever are merely a reaction by a confused sensory nervous system. The sensory nerves are malfunctioning due to the elevated body heat. The real problem is the fever, not cold!

  My histology professor maintained that the reason you turn on a hot shower and instantly interpret the water as cold just before you are scalded is because the body's surface possesses far more cold receptors than heat receptors, and that your sensory nervous system is overwhelmed by the cold first. (This is stated with the assumption that the hot water is already present in the pipes.)

Reflective Stories

Story #1—During the early 90s, I worked in a health club that attempted to instruct personalized SuperSlow protocol amidst a general clientele paying monthly dues to self-train. One morning, a middle-aged woman started her self-supervised workout on leg press after first turning off every fan in the room. I told her that the fans were required by the other subjects, as they would also be by her once she got deeper into her workout. She then insisted that they be off, because she was suffering from chills. At that, I became alarmed and tried, unsuccessfully, to convince her that a workout would only serve to cripple her body's healing mechanism. She regularly trained three times per week; yet I next saw her three weeks later, dramatically coughing and admitting that she had lost three weeks work due to illness. We can only speculate that the workout contributed to the length of her convalescence.

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Story #2—I regularly supervise the SuperSlow workouts of a young girl who weighs more that 300 pounds. She commented that her original attraction to our studio was overhearing that we keep the room cool with copious ventilation. Due to her size, the usually hot, humid training environment of the other local gyms makes her sweating and overheating unbearable and dangerous.

Story #3—I have supervised one woman since 1991 who for years would not allow me to aim fans at her. Then, about six years ago, we sustained a hurricane that knocked out the electricity to her neighborhood, causing damage to her air conditioner that could not be repaired for several weeks. As this occurred in the hottest part of the summer, she and her family were miserably hot. Since then, she has demanded, almost indignantly, the fans be placed on her throughout her workouts.

Story #4—I presently supervise a 50-year-old woman who is very strong, perhaps twice as strong as the normal woman. She is willing and able to train intensely; therefore I expect her to produce abnormally more body heat than the typical woman. On the contrary, she is cold throughout the workout and often shivers noticeably during leg press—that exercise that involves the largest muscular structures. After months of me openly supposing that she had a strange metabolism or endocrine imbalance, she began to ask for, then demand, a fan. I believe that these behavior changes are indicative of increased metabolism. Perhaps, in some cases, they are simultaneous with menopausal hot flashes.

Story #5—In the later years of my Nautilus career, I knew an architect who ventured away from Nautilus to form his own company specializing in exercise studio layout and furnishings. I recognized that, although a good architect, he had no clue to the exercise requirements for heat dissipation. And as I observe most of the fitness industry, the same ignorance prevails as represented in apparel and paraphernalia for exercise.

Saunas and Whirlpools Saunas and whirlpools are blatant contraindications for use with exercise studios. To heat the body through intense exercise and then to expose the subject to hot air or water is asking for medical trouble. Or to preheat the body by these or other means prior to exercise is similarly irresponsible.

Yoga and Boxing Sects I am loosely aware of several backwards philosophies of exercise which actively promote their activities in heated environments to promote sweating. Such malpractices underscore the need to educate the general public to these dangers.

Certification Programs It is obvious to me that, among many other important issues, the issue of heat production and dissipation is sorely missing from almost all exercise certification programs. And this reveals the fact that the exercise physiologists who write and advise these programs are wholly ignorant of this part of physiology.

Hydration I would bet that many readers are now wondering why I haven't devoted more attention to hydration as it concerns heat dissipation. I haven't because it is often overrated for the purposes of proper exercise. In some cases, hydration fanaticism has led to unnecessary injuries. I will explain.

It is now commonplace to observe the posh gym rat carrying the trendy water bottle as standard paraphernalia. Within the past year I have witnessed several close calls with clients who have

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mindlessly staggered about in the gym between exercises simultaneously sipping on their water bottle. In one case—in a large gym about a mile away from my establishment—a novice subject stumbled while reaching for his water bottle immediately after his workout. He fell into a machine and subsequently sued the machine manufacturer, his instructor and the business.

The issues are as follows:

- The exercise subject must focus on one thing—walking—as he struggles to walk after exercise.
- The subject must keep his hands free for balance as well as available for assistance.
- The subject must keep his neck in a neutral position as he transfers from one exercise to another—not cocked upwards and/or turned to suck water through a straw or sip from a vessel.
- The subject must retain optimal visibility to avoid tripping or colliding with other subjects or equipment. A water bottle held to the face obscures part of his vision.
- The subject must not place the bottle on the floor for others to negotiate.
- The subject must avoid bending, especially with unexpected and uncontrolled trunk twisting and/or stooping to lift the bottle off the floor as this multiplies and complicates risk to the spine

Although I have discouraged excess baggage—including water bottles—in my workout area, I have permitted some clients their water bottles. In one case, a lady was on high dosages of lithium that kept her airway extremely dry and necessitated a drink between every exercise, sometimes during an exercise—a very unusual requirement.

In another case, I permit a veteran client to keep her bottle in the room, but not carry the bottle, and only drink between the lower and upper body segments of the routine. In so doing, I am required to hide the bottle from her so that she cannot reach it during the segments. I also stand to block her movement as she drinks to prevent her simultaneous walking.

A drink of water can actually serve advantageously to the workout in an often unsuspected way. If someone is, indeed, going to drink water between exercises, it should be done at some designated halfway point in the routine—again, perhaps between the upper and lower body segments. And, it should force a slight and measured—perhaps one minute—respite between these segments. For instance, with some subjects on some routines, I routinely send the subject out of the gym and into the reception area to get a sip of water—not because he needs water—he does not—but to get his wits so that he can refocus and perform the next segment of exercises with added intensity. Having him walk out of the room is part of the strategy. Having a handy water bottle defeats this strategy to some degree.

Bear in mind again that there is often a balance between the desired intensity and the subject's ability to think. Once intensity obscures intellectual function, then intensity suffers.

In an ideal environment, continued hydration with most subjects during exercise is a minor concern. As already stated, the workout is conducted in a cool, ventilated and low-humidity area.

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And the workout, properly performed, is, though intense, relatively brief—10 to 20 minutes. Under these conditions the exposure is not sufficient to send the body to its threatening limits.

There are exceptions, however. Consider the possibility that the subject is an athlete who has just come in from a three-hour practice in the hot, humid Florida climate. He arrives grossly dehydrated. This subject should probably tank up on the water before starting his workout.

Other special cases may deserve preemptive care for dehydration. They include alcoholics, diabetics and hypertensives. These populations tend to incur dehydration due to substance abuse or their medications.

Economic Concerns

I sometimes hear a health club owner rebel against my recommendations for the ideal environment because they fear the cost of keeping that environment cool—in other words, air conditioning costs. There do exist considerations that serve to offset those costs.

Consider the fact that a humid environment is unsanitary, that it is conducive to growing bacteria and other pathogens. Sweat accumulating on upholstery is a means to transport these pathogens between people. Therefore, the constant cost of cleaning supplies and janitorial labor, in addition to citations by local health departments should be reduced within an environment to that minimizes sweating.

Sweat accumulation is also a big threat to upholstery. Salty sweat leads to premature cracking, weakening and tearing of upholstery. In addition to the replacement cost already mentioned, the greatest cost is sometimes the downtime for the equipment.

Another oversight by club owners is the damage sweat and salty air does to the metal parts of the exercise equipment. Most successful club owners would avoid leaving their luxury cars at the beach for fear of accelerated corrosion, but then fail to see the same problem occurring on a daily basis in their business due to the hot, humid, salty gym air.

Hydration and Its Effect on Metabolism

For several years now we have heard that drinking copious amounts of cold water serves to burn more calories, thus promoting fat loss. Although an important metabolic issue, this subject is beyond the scope of this article. Any de-emphasis herein regarding hydration for exercise purposes is not intended as recommendation toward the metabolic issue.

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