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The interrelationship between air temperature and humidity as applied locally to the skin: The resultant response on skin temperature and blood flow with age differences

Authors' Contribution:

- A** Study Design
- B** Data Collection
- C** Statistical Analysis
- D** Data Interpretation
- E** Manuscript Preparation
- F** Literature Search
- G** Funds Collection

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Background:

Most studies of the skin and how it responds to local heat have been conducted with either water, thermodes, or dry heat packs. Very little has been accomplished to look at the interaction between air humidity and temperature on skin temperature and blood flow. With variable air temperatures and humidity's around the world, this, in many ways, is a more realistic assessment of environmental impact than previous water bath studies.

Material/Methods:

Eight young and 8 older subjects were examined in an extensive series of experiments where on different days, air temperature was 38, 40, or 42°C. and at each temperature, humidity was either 0%, 25%, 50%, 75%, or 100% humidity. Over a 20 minute period of exposure, the response of the skin in terms of its temperature and blood flow was assessed.

Results:

For both younger and older subjects, for air temperatures of 38 and 40°C., the humidity of the air had no effect on the blood flow response of the skin, while skin temperature at the highest humidity was elevated slightly. However, for air temperatures of 42°C., at 100% humidity, there was a significant elevation in skin blood flow and skin temperature above the other four air humidity's ($p < 0.05$). In older subjects, the blood flow response was less and the skin temperature was much higher than younger individuals for air at 42°C. and 100% humidity ($p < 0.05$).

Conclusions:

Thus, in older subjects, warm humid air caused a greater rise in skin temperature with less protective effect of blood flow to protect the skin from overheating than is found in younger subjects.

key words:

thermoregulation • humidity • ageing • skin

Summary

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BACKGROUND

The skin serves as a barrier between the internal organs and the outside world [1,2]. It also serves as a media for heat exchange much like the radiator in a car [1,3–5]. The internal body temperature (core) is much higher than the skin temperature (shell tissue) [6]. This allows for the movement of heat down a thermal concentration gradient to allow the body to dissipate heat from metabolism [7,8]. Movement of heat to or from the skin is through the passive heat exchange properties of the skin and the ability of the circulation to change [9]. Skin circulation is controlled through the sympathetic nervous system [10], mediated by vascular endothelial cells releasing vasodilators such as nitric oxide [11]. When local heat is applied to the skin, these same vasodilators respond to increase skin circulation and protect the skin from damage [6,8]. Here there is a biphasic response, the initial response to heat is mediated by substance P and calcitonin gene related peptide [12–14] released from tactile sensory nerves while the sustained response to local heat is mediated by nitric oxide and prostacyclin [15].

While these general principals have been accepted for several decades, there are several factors that modulate this response. For local heat, for example, if electrical stimulation is applied to the skin at currents less than 20 milliamps when the skin is warmed at the same time, the blood flow response of the skin is greater than that of the heating alone [12,16]. Conversely, if the skin is cooled, blood flow is reduced in proportion to the skin temperature. When the skin is cooled to 30°C, the same electrical stimulation has no effect on skin blood flow [17]. This phenomenon is explained best by the fact that multiple stimuli operate through the same voltage gated channels on vascular endothelial cells. A type of voltage gated calcium channel, the TRPV4 channel, is common to transduction of vertical pressure, shear pressure, sensation for warmth, response to acetylcholine and other environmental factors which effect the vascular endothelial cell [18]. By sharing the same receptor, these stimuli interact with each other. TRPV4 channels also sense cell osmolarity. Previous work has shown that if the cell osmolarity is low, then the blood flow response to heat is high while cell osmolarity reduces the blood flow response to heat [10]. What isn't known is if the interaction between skin moisture and heat is a linear or exponential response. In other words, if you double the moisture in the

skin, do you double the skin blood flow response to heat? A complicating factor is age. As skin ages, there is a natural senescence in the blood vessels involving increased free radicals [19] and rarefaction of the circulation [20,21]. In addition, there is thinning of the dermal layer with ageing [22,23] reducing its ability to remove heat from the surface of the epidermis [5,22,24,25]. Skin also loses its lipid content, dries and is easily irritated, e.g., contact dermatitis, and repairs slowly [11,26].

The reduction in the blood flow response to heat with ageing may be linked to reduced skin moisture; this relationship has not been examined. The purpose of the present investigation was to observe the blood flow and skin temperature in younger and older individuals in response to heat supplied by air at different humidity's. Almost all studies on the blood flow response to heat have been accomplished using water baths or a dry heat source. Moist air may have several different effects from dry air. First, moist air carries more calories. This is due to the higher heat coefficient of moist air [27]. Second, moist air will hydrate the skin and alter the blood flow response of the skin at a set temperature [17]. This has never been examined in human skin. In male and female subjects at different ages, skin temperatures were brought to 38, 40, or 42°C for 20 minutes. At each temperature, the skin moisture was adjusted to either 0,25,50,75 or 100%. This allowed the interactions between skin moisture, temperature and ageing to be assessed.

MATERIAL AND METHODS

Sixteen subjects participated in these experiments. The subjects were divided into two groups; one group was the young group and the other group was the older subjects. Subjects had no diagnosed cardiovascular disease, were not taking any medications that would affect the cardiovascular system and had no known peripheral circulatory diseases. Subjects were not taking alpha or beta agonists or antagonists. Subjects did not have diabetes. The general characteristics of the subjects are in Tables 1 and 2 below. There was no statistical difference between the subjects except for age. All protocols and procedures were approved by the Institutional Review Board of Loma Linda University and all subjects signed a statement of informed consent.

Table 1. General characteristics of younger subjects.

	Age (years)	Height (cm)	Weight (kg)	BMI	% fat
Mean	26.8	170.4	69.0	23.4	22.4
Standard deviation	3.2	9.9	17.0	4.0	5.3

Table 2. General characteristics of older subjects.

	Age (years)	Height (cm)	Weight (kg)	BMI	% fat
Mean	68.3	159.6	86.6	34.0	34.6
Standard deviation	10.7	17.0	19.5	5.6	6.0

Methods

Skin temperature

Skin temperature was measured with a thermistor (SKT RX 202A) manufactured by BioPac systems (BioPac Inc., Goleta, CA). The thermistor output was sensed by an SKT 100 thermistor amplifier (BioPac Inc., Goleta, CA). The output, which was a voltage between 0 and 10 volts, was then sampled with an analog to digital converter at a frequency of a 1,000 samples per second with a resolution of 24 bits with a BioPac MP150 analog to digital converter. The converted data was then stored on a desktop computer using Acknowledge 9.1 software for future analysis. Data analysis was done over a 5 second period to measure mean temperature. The temperature was calibrated at the beginning of each day by placing the thermistors used in the study in a controlled temperature water bath which was calibrated against a standard thermometer.

Measurement of skin blood flow

Skin blood flow was measured with a Moor Laser Doppler Imager. The imager used a red laser beam (632.8 nm) at a power of 2.5 mw to measure skin blood flow using the Doppler Effect. The laser, in this case, was used in single point mode. After warming the laser for 15 to 30 minutes prior to use, the laser was focused through the capsule and on the skin, and by comparing the reflected to the source light, the change of the frequency of the light and absorption of the light was used to calculate the red cell velocity and the red cell content in that area of the skin. The Moor Laser Doppler Imager measured blood flow through most of the dermal layer of the skin but did not penetrate the entire dermal layer. Blood flow was then calculated in a unit called Flux based on the red cell concentration and red cell velocity with a stated accuracy of $\pm 10\%$. The tissue thickness sampled is typically 1mm in depth.

Measurement of airflow

Airflow was measured with a Fox inline flow meter (Fox Measurements, Marina California). The sensor had a $\frac{1}{2}$ inch inlet and measured air flow to 10000 cc/sec. By using a thermal dilution principal, the flow meter provided gas temperature and flow of air linearly.

Measurement of skin moisture

Skin moisture was measured with a Corneometer 810 capacitance skin moisture meter (Courage Khazaka Electronics, Koln, Germany). The moisture was in units of between 1 and 100. The Corneometer has been validated in numerous studies. It used tissue capacitance assessed by applying electromagnetic waves at a frequency of 100,000 cycles per second to image the skin surface [28,29]. It has been used extensively to evaluate the effect of different treatments on skin conditions [30]. The Corneometer, when used at a frequency at a 100,000 cycles per second, measured skin moisture only to the bottom of the dermal layer [31,32].

Control of skin temperature

Compressed air was supplied by a central air compressor with a 1000 liter reservoir and adjusted to a pressure of 10

bars. A dryer on the tank eliminated much of the trapped moisture and a fan kept the tank at near room temperature. In such a system, air pressure varies up and down when the motor cycles on and off on the compressor as the pressure sensor senses a pressure drop and engages the pump. The variation in pressure was ± 0.2 Bar. To stabilize this pressure variation, the air supply was down-regulated into a 40 liter pressure reservoir at a pressure of 2 bars. The low pressure reservoir had a moisture collection chamber to remove excessive moisture that might be in the lines from the main air supply. The tank was made of metal and cooled with a fan. The output of this pressure reservoir then passed through 15.3 meters of copper tubing which was 63.5 mm in diameter. The tubing was submersed in a well stirred and temperature regulated water bath with a volume of 0.1 meters³ so that the air was brought to the desired temperature for the study. The temperature of the water in the bath was regulated by a Fisher model 2100 Isotemp heater (Fisher Scientific, Waltham Mass) digital temperature regulator with 1000 watts of heat capacity and a water stirring motor. This kept the water temperature to less than $\pm 1.0^\circ\text{C}$ in the bath. The air pressure at this point was 0.5 Bar. The warmed air was then separated through 2 air flow valves (Key Instruments MR3000 series, Treviso, PA) capable of regulating air flow up to 1500 cc/sec. The 2 separate air paths then routed air through either a pressurized container of Drierite (Hammond Drierite, Xenia, OH) or through a 2 liter glass bottle filled with water and also lying in the water bath. The air pressure after the water bottle or Drierite was reduced to 0.26 bar.

A bubbler made of perforated copper pipe in the bottom of the water bottle saturated the air with water as it moved from the bottom to the top of the bottle. Since the bottle was placed in the water bath, the moist air was at the bath temperature. A fiberglass layer near the outlet valve in the bottle kept water from entering the exhaust line. The two sources of air, one dry and one at 100% humidity then were mixed and traveled through a 15.24 meter piece of 63.5 mm diameter copper tubing in the water bath (LxWxD, 92.5x38.9x39.8 cm). This allowed the mixed air to remain at the desired temperature. Here the air pressure was now 0.02 bar. As it left the tubing, the air flowed through a humidity and temperature sensor (Extech, Heavy Duty Moisture Meter #407777, and Waltham, MA). The sensor was a combined calcium chloride moisture sensor with a thermistor for temperature of the mixed gas. The sensor chamber itself was sealed. The air pressure at the output of the sensor was 0.01 bar. The pressure reduction through the lines created a problem as the gas emerged from the submerged coils in the water bath. The drop in pressure was enough to cause adiabatic cooling which, for moist air, caused the air to condense as before it arrived at the skin. To prevent this, the air flow lines to and from the capsule and the capsule itself were temperature controlled. The airlines were all covered with 63.5mm diameter plastic tubing which also carried water which circulated from a pump in the water bath such that the temperature of the sensor and air lines were maintained near bath temperature. The water flow lines were arranged with the line closest to the body connected to the bath and the return was placed near the bath. This was used to make the heat delivery system a counter current multiplier. The capsule that was in contact with the skin was rectangular with dimensions of 28.11 mm height, 47.95 mm width, 49 mm length and 10.27 mm thickness. A

water jacket was integrated into the capsule. Water from a pump perfused the capsule with water to maintain capsule temperature at bath temperature. Thus by adjusting the two flow meters on the moist and dry air sources, any possible combinations of temperatures and humidities could be set into the capsule in contact with skin. A hole which was 8.64 mm in the diameter in the center of the capsule allowed a Laser to penetrate the capsule and provide the skin blood flow during the heating process.

Procedures

Subjects entered a thermally neutral room (22°C) and rested comfortably for 20 minutes. Baseline blood flow was recorded for 1 minute. After this period of time, the thermode was placed upon the arm above the brachioradialis muscle. The thermode was placed on the arm for 20 minutes. On different days, air temperature was 38, 40, or 42°C for 20 minutes. At each temperature, the moisture (humidity of the air) was adjusted to 0, 25, 50, 75 or 100% humidity. This allowed the interactions between skin moisture, temperature and ageing to be assessed. Skin moisture was measured before and after the 20 minute period and blood flow measured continuously.

Analysis of data

Analysis of data involved the calculation of means and standard deviations and related and unrelated T tests. Data was analyzed on Excel. The level of significance was $p < 0.05$.

RESULTS

The results of the experiments are shown in Figures 1–6. As shown in Figures 1–3, the resting blood flow in the skin was lower in the older subjects than was seen for the younger subjects. Averaging the resting blood flow for all subjects for all 3 temperatures and all 5 humidity's, the average resting blood flow was 123.3 ± 23.2 flux in the younger subjects, and 113.5 ± 11.3 flux in the older subjects. This difference was significant ($p < 0.05$). For the young subjects, when air was then applied to the skin at a temperatures of 38°C. (Figure 1A) the skin blood flow increased immediately and throughout the entire 20 minute exposure. There was no significant difference in the blood flow response seen in the young subjects for air applied to the skin at 38°C. at any time period during the 20 minutes when comparing the blood flow response with dry air, or air at 25%, 50%, 75%, or 100% humidity. The average blood flow increased to 405.4 ± 85.3 flux at the end of the 20 minutes for all 5 humidity's, averaging the blood flows for all 5 experimental conditions in the younger subjects. In contrast, as shown in Figure 1B for the older subjects, the blood flow also increased steadily throughout the 20 minute exposure period to air, and while there was no significant difference between any of the 5 experimental conditions (ANOVA $p > 0.05$), the final blood flow at 20 minutes was significantly less in the older subjects than the younger subjects. In fact, for the older subjects, blood flow peaked at 18 minutes and by 20 minutes blood flow had reduced from a maximum of over 350 flux to 274.1 ± 83.2 flux. Thus, blood flow was at least 30% higher at 20 minutes in the young subjects than in the older subjects after the skin was exposed for 20 minutes to air at 30°C.

When air was warmed to 40°C. and applied to the skin in the younger subjects (Figure 2A), a similar response was seen. As

was seen for air at 38°C., blood flow rose continuously throughout the 20 minute exposure. However, at the end, blood flow was significantly higher averaging 577.1 ± 101.3 flux, approximately 50% higher at the end of the 20 minute exposure to the 40°C. air than the 38 °C. air in the younger subjects. For the older subjects, as shown in Figure 2B, when air was blown across the skin at 40°C., skin blood flow rose continuously, but as seen in Figure 1B, after 16 minutes, the blood flow decreased to the 20 minute point. Even at 16 minutes, the peak blood flow was significantly less than was seen for the younger subjects either at this period or at the end of the 20 minute period ($p < 0.05$). At 16 minutes, the average blood flow for the 5 experimental conditions for the older subjects was 446 ± 97.3 flux.

When air was applied to the skin at a temperature of 42°C., the pattern of response for both the young subjects (Figure 3A), and older subjects (Figure 3B) was different than the other 2 temperatures. As was seen for the other 2 temperatures, skin blood flow rose continuously from rest throughout the 20 minute exposure period for the younger subjects (Figure 3A), and, as was the case for the older subjects after the other 2 temperatures, from the 16th minute there was a reduction in blood flow. However, for the younger subjects, there was a clear distinction. As shown in Figure 3A, the skin blood flow for air at 100% humidity was significantly higher at every point in time after the air was applied than was seen for exposure to dry air, 25%, 50%, or 75% humidity (ANOVA $p < 0.01$). The same phenomenon was seen for the older subjects except that for the older subjects, the increased blood flow response was smaller than that seen for the younger subjects, and the blood flow was still significantly less at any measuring period for the older subjects than the younger subjects ($p < 0.05$).

The skin moisture measured with a Corneometer paralleled much of these findings. For air at 38°C. and 0% humidity for example, skin moisture started at 34.4 ± 9.7 in the younger subjects and ended at 33.3 ± 8.81 . At 50% humidity, skin moisture began at 34.1 ± 9.1 and ended at 39.5 ± 9.5 , a significant increase ($p < 0.05$). At 38°C. and 100% humidity however, moisture increased very significantly from 36.9 ± 7.9 to 80.3 ± 27.9 ($p < 0.01$). This greater hydration of the skin with 100% humidity air was also seen for air at 40°C. and 100% humidity, where skin moisture in the young subjects increased from 37.8 ± 14.1 to 62.1 ± 18.9 , and 42°C. air where skin moisture increased from 40.7 ± 8.4 to 70.2 ± 21.1 .

For the older subjects, skin moisture increased but much less. For example, at 38°C. dry air, skin moisture changed from 34.7 ± 3.9 to 35.9 ± 6 a non-significant difference ($p > 0.05$). At 38°C. air temperature and 100% humidity applied to the skin, moisture changed from 36.9 ± 10.1 to 63.7 ± 30.1 , a significant increase ($p < 0.01$). At 42°C. air and 100% humidity, skin moisture increased from 32 ± 12.8 to 65.5 ± 23.8 , also a significant increase ($p < 0.01$).

When looking at the skin temperatures, skin temperature increased continuously for all subjects for all 3 exposures to air at 38, 40, and 42°C. However, as shown in Figure 4A, for the younger subjects exposed to air at 38°C. for 20 minutes, the average temperature of the skin was only about 36 degrees C. Further, for the moist air, there was a more rapid rise in skin temperature ($p < 0.01$) as shown in Figure 4A during the first 5 minutes. For the older subjects with air

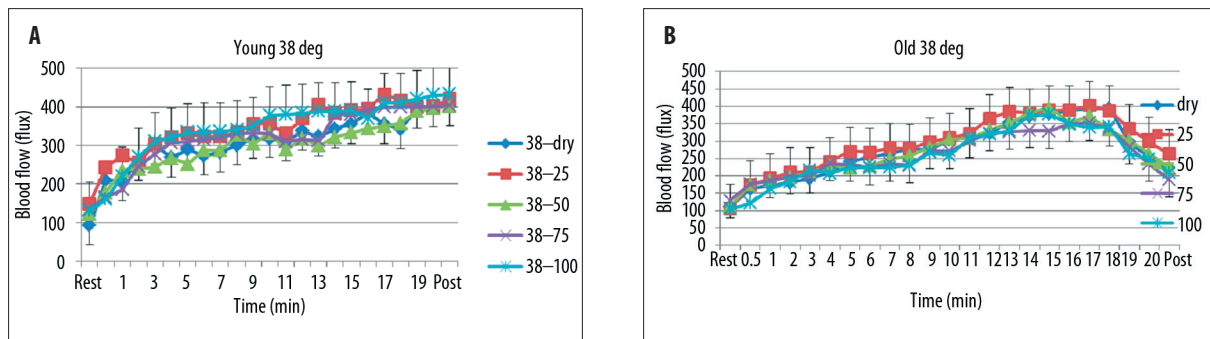


Figure 1. Illustrated here is the relationship between the skin blood flow and the duration of the heat exposure (x-axis). Skin blood flow is in flux on the y axis and each point represents the mean of all the subjects in the group \pm the respective standard deviation for experiments with air at 25%, 50%, 75%, and air at 100% humidity. (A) shows young subjects, and (B) shows older subjects throughout exposure to air at 38°C.

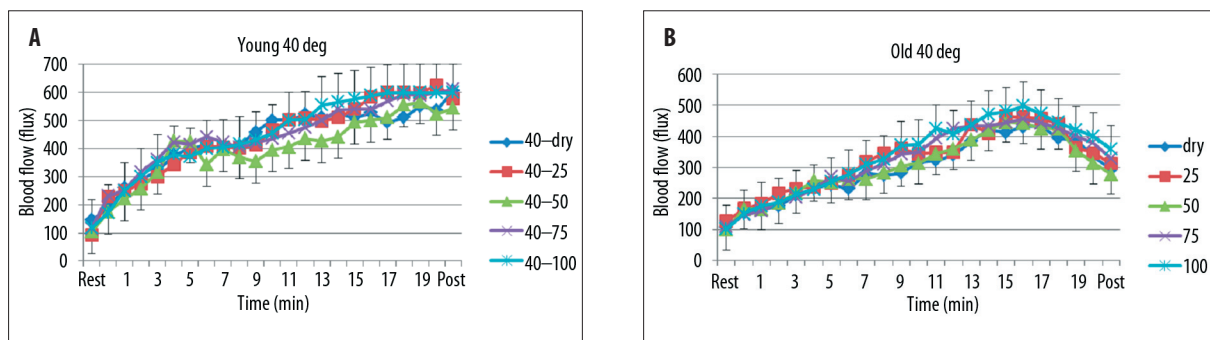


Figure 2. Illustrated here is the relationship between the skin blood flow and the duration of the heat exposure (x-axis). Skin blood flow is in flux on the y axis and each point represents the mean of all the subjects in the group \pm the respective standard deviation for experiments with air at 25%, 50%, 75%, and air at 100% humidity. (A) shows young subjects, and (B) shows older subjects throughout exposure to air at 40°C.

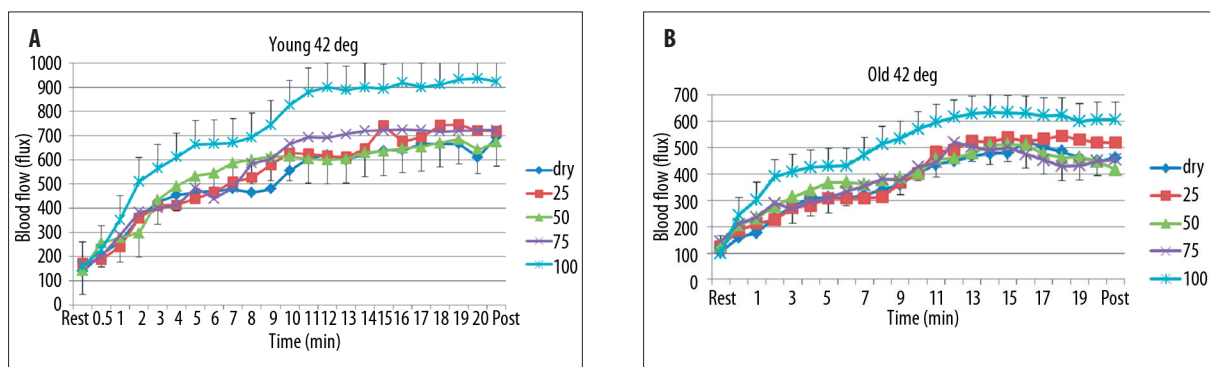


Figure 3. Illustrated here is the relationship between the skin blood flow and the duration of the heat exposure (x-axis). Skin blood flow is in flux on the y axis and each point represents the mean of all the subjects in the group \pm the respective standard deviation for experiments with air at 25%, 50%, 75%, and air at 100% humidity. (A) shows young subjects, and (B) shows older subjects throughout exposure to air at 42°C.

at 38°C. their skin temperature was not significantly different for humidity's of 0%, 25%, 50%, and 75%. However, skin temperature at 100% humidity was significantly higher in the older subjects than the younger subjects ($p < 0.05$).

When air was applied at 40°C., skin temperature was progressively higher as shown in Figure 5A (young subjects), and Figure 5B (older subjects). However, here, for both the young and older subjects, the skin temperature rose faster and was significantly higher with air at 100% humidity than for dry, 25%, 50%, and 75% humidity air.

This was also seen for air at 42°C. where for all humidity's below 100%, skin temperature rose to an average of about 38°C. for the young subjects and slightly higher for the older subjects (Figure 6A, B), but for the younger subjects and older subjects, air at 100% humidity caused the skin to rise to the temperature of the air that is 42°C.

DISCUSSION

Numerous studies have shown that when heat is applied to the skin in man, blood flow increases [8,33]. Part of the increase in blood flow is certainly protective in nature

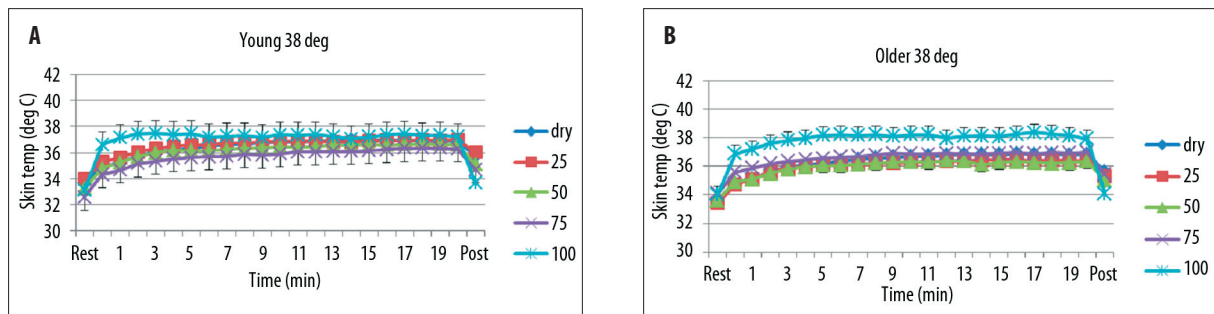


Figure 4. Illustrated here is the skin temperature (°C.) recorded from the skin on the forearm at rest and throughout the 20 min exposure, where the skin was exposed to air that was either dry or at 25, 50, 75, or 100% humidity. Each point represents the mean of all subjects \pm the respective standard deviation. The air temperature here was 38°C. (A) represents young subjects and (B) represents the older subjects.

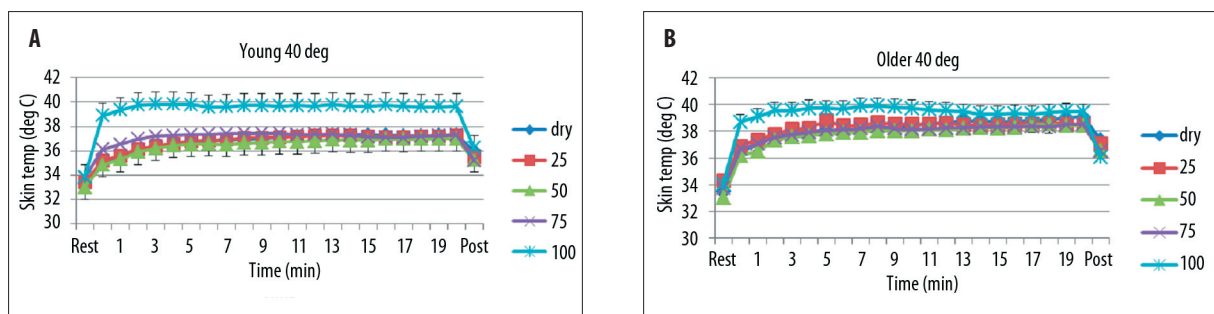


Figure 5. Illustrated here is the skin temperature (°C.) recorded from the skin on the forearm at rest and throughout the 20 min exposure, where the skin was exposed to air that was either dry or at 25, 50, 75, or 100% humidity. Each point represents the mean of all subjects \pm the respective standard deviation. The air temperature here was 40°C. (A) represents young subjects and (B) represents the older subjects.

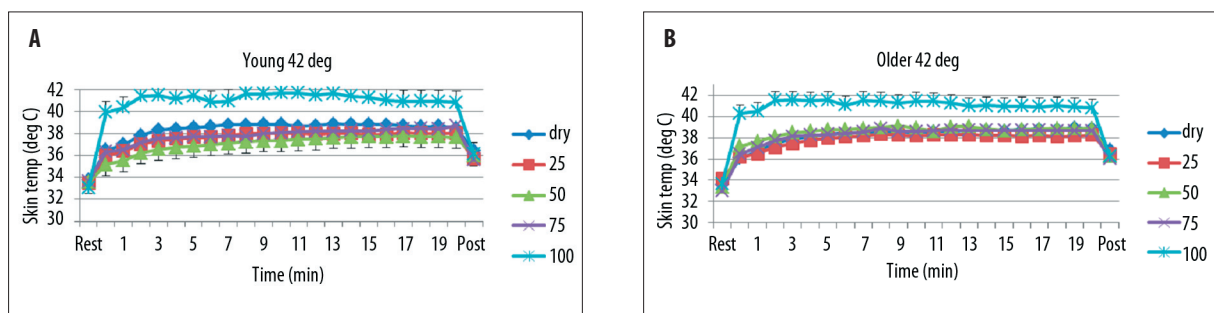


Figure 6. Illustrated here is the skin temperature (°C.) recorded from the skin on the forearm at rest and throughout the 20 min exposure, where the skin was exposed to air that was either dry or at 25, 50, 75, or 100% humidity. Each point represents the mean of all subjects \pm the respective standard deviation. The air temperature here was 42°C. (A) represents young subjects and (B) represents the older subjects.

to avoid burns and the rest to dissipate heat[24]. The response to heat is biphasic. In the first phase, skin tactile receptors cause an increase in blood flow lasting several minutes mediated by substance P and calcitonin gene related peptide [3,5,13,17,34]. The sustained response for heat continuously applied to the skin is mediated principally by the vasodilators nitric oxide and prostacyclin [34,35]. However, aging blunts this response both for the immediate response to heat and the sustained response to heat [5,18,36]. But many of the studies conducted on heat in the skin have used either a thermode, a device that transfers heat to the body without moisture [37,38], or have used water baths [39,40]. In the real world, the skin is exposed to air, especially in the west, where air is sometimes warm air but at various humidity's. The effect of humidity and warm air on the skin has not been investigated.

In the present investigation overall, for any given set of conditions, including at rest, the skin blood flow response of the older subjects was significantly less than that of the younger subjects. As cited above, this is to be expected since numerous papers have shown multiple impairments associated with local vasodilation and response to heat in older people [22,25,41,42]. These include, reduced tactile sensitivity for nerves in the skin which would reduce the immediate response heat [43], and reductions in both the prostacyclin mediated and nitric oxide mediated vasodilator pathways in sustained response to heat [44]. The present investigation agrees with other published studies on the local response to heat in older versus younger individuals. However, this study differed in that it used air instead of a thermode or a water bath to warm the skin. The blood flow response was similar in the younger subjects for air at

38 and 40°C. However, in the same group of subjects, for air at 42°C. and 100% humidity, there was both an increase in skin temperature, and the blood flow response was higher than it was for air at 0%, 25%, 50%, or 75% humidity. This was also true for the older individuals. As the humidity of the air was increased, sweating would be less effective in cooling the skin. This is due to the fact that sweat cannot evaporate when air is at 100% humidity [45]. For air at 38°C. in the younger subjects, this was not a major issue in that the higher skin blood flow was still able to maintain skin temperature by removing heat from the skin as predicted by Pennes [8]. However, even for air at 38°C., in the older individuals, skin temperature rose several degrees warmer for air at 100% humidity.

For air at 40°C., skin temperature also was several degrees warmer in both the younger and older individuals for air that was 100% humidity, and yet the blood flow was not higher. Pennes, in a classic model of the skin which has been confirmed in numerous studies, showed that dissipation of heat from the skin takes place through both blood flow and conduction due to the passive heat transfer properties of the skin [8]. Skin and subcutaneous fat, while not allowing the heat to transfer very quickly when circulation is intact, still can dissipate substantial amounts of heat especially from a small capsule heat source such as the one shown here [8,46,47]. Therefore, although in both the younger and older individuals the skin temperature rose higher for exposure to 100% humidity air at 40°C., the skin blood flow response was still the same. In contrast, at 42°C. in both the older and younger individuals, there was a substantial increase in skin temperature by almost 2°C. above that seen in the younger subjects when compared to the older subjects. Because of the higher heat load, and greater increase in skin temperature, this did trigger a greater increase in circulation in both the younger and older individuals than that seen for all other air humidity's. The increase in skin blood flow for the young and old subjects was out of proportion to the increase in skin temperature. For example, when skin temperature was recorded after exposure to air at 38 compared to 42°C, the skin warmed by 2°C and flow increased by about 200 flux. But with moist air, the increase in skin temperature for the exposure to the 42°C air, while being about 2°C raised flow by over 300 flux. This greater increase in flow then is probably related to both the increase in skin moisture and temperature which have been shown to potentiate the skin blood flow response. The fact that air at 38 and 40°C did not cause an increase in circulation although skin moisture increased may be related to skin temperature. In other studies, it was shown that the TRPV4 channels can have a modulated response to stress such as electrical stimulation if the skin is cold [48]. This receptor, since it responds to multiple stimuli, can be down or up regulated depending on the sum of the stimuli applied. It is possible that the skin temperature was not high enough to see an effect of the osmo receptors in the skin after exposure to the 2 cooler air temperatures.

CONCLUSIONS

For air at 100% humidity at a temperature of 42°C, both skin temperature and skin blood flow rose above that seen with lower humidity for air exposure. It is surprising that air at 50% and 75% humidity did not elicit such a response.

However, the skin did not moisturize well at lower humidity's and therefore, the drier skin may reduce some of the increase in circulation that should have been seen here. It appears that lower humidity air (less than 100% humidity) is much safer on older and younger individuals than air at 100% humidity. Air at 100% humidity however is common in the summer in many parts of the United States especially during the heat of the day. Further, saunas use similar or higher temperatures at 100% humidity, and thus would elicit a much larger increase in circulation than other humidity's.

However, this study was only conducted on less than 20 subjects. Furthermore, only one air flow rate was assessed. Additional studies should be conducted at lower and higher air flow rates to see if the same findings would apply to low rates of air or very high rates of air flow.

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