Dynamics of Human Thermal Signatures

Barbara L. O'Kane, US Army Night Vision
Philip Sandick, Columbia University
Todd Shaw and Mike Cook, EOIR Technologies, Inc.

ABSTRACT

It is well known that thermal imagery is dynamic and sensitive to the physiological processes in the body, with heat transfer from physiological processes affecting the surface temperature of the skin. This paper describes a period of exploratory research in which thermal imagery was collected for analysis of human signatures to determine "what to look for where" in the understanding of human internal states and recent or ongoing physical activities. Several short imagery collections and analyses are described and discussed in terms of their relation to an overall view of the thermal signature.

This work builds on previous experience by some of the authors in understanding and identifying tactical vehicles. With tactical vehicles the goal was to determine the cues to identity and where they lay, in order to prevent fratricide; the goal of the present series of studies is to assess the relevant signature attributes of people in motion. It seeks to determine where the chief cues are to human activities in the thermal signature and to interact with the biometrics, non-lethal effects, stress and motivated behavior, and medical communities. The potential for revealing internal states of the human, such as anxiety, excitement, recent aerobic or strength-related activities, has yet to be fully explored and understood. What can be seen in the thermal image has yet to be quantified and interpreted. Through an overarching view of the normal human thermal image, the science of the human body may be advanced.

KEYWORDS: human thermal signature, IR signatures, infrared, thermograph, people, exercise imagery

INTRODUCTION

Thermal imagery is a part of the military toolbox that represents a well-established field method for detecting and recognizing military vehicles [1]. The typical soldier is now trained in the identification of vehicles through all kinds of sights, and thus the risk of misidentification and fratricide has been much reduced. Now that the human is in close operations to civilians, including women, children, and non-combatants, the understanding of the typical human signature is tantamount for recognizing them. However, in comparison to vehicles, the human is relatively unexplored from the standpoint of its thermal signature. Basic understanding of the human thermal signature in everyday life is a first step along the way to determining the usefulness of thermal imagery for applications of technology involving the human.

OBJECTIVE OF THE RESEARCH STUDIES

The objectives of this small research study were to:

Develop an understanding of where the changes in the human thermal signature are most robust and conspicuous during various typical activities.

Emphasize the thermal signature of the face to gain insight on the perception of cognitive and emotional states.

Understand the patterns in the imagery to provide rules for interpreting the perception of changes.

APPROACH

Two FLIR cameras were used in the studies: the ThermaCAM® SC 1000 and ThermaCAM SC 2000, mid- and long-wave calibrated cameras, respectively. Each has 320 X 240 pixels; no extra lenses were used in the capturing of imagery for these studies. The results were analyzed with ThermaCAM Researcher 2001 software.

BLOOD VOLUME IMAGERY COLLECTION

When an individual holds his or her hand in a lowered position, the blood tends to pool in the veins of the hand. This fact can be easily seen with the naked eye. The question in the first imagery collection was: “What change could be seen in the thermal image as the hand is held in a downward position, and the blood vessel appears to fill?” Figure 1 shows a picture of the hand as taken with the ThermaCAM SC 2000 camera during imagery collection.

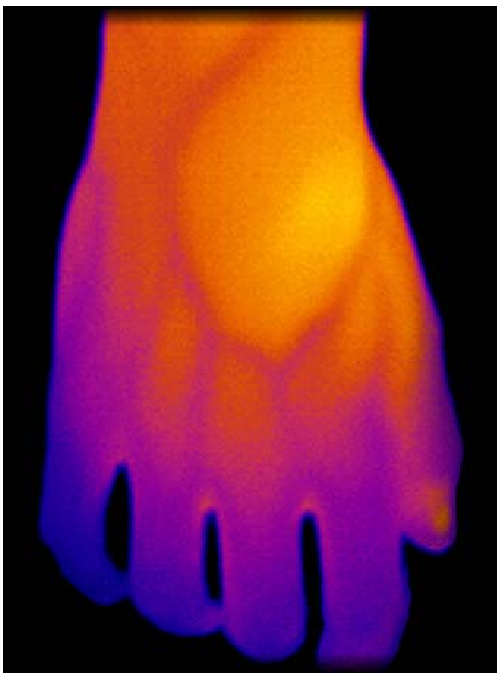


Figure 1. Thermal image of hand held down. Notice the vein structure is cooler than the surrounding skin and very visible.

It was expected that the location of the “vein merge” (Figure 2, light blue area), where the blood tended to pool, would get warmer. However, the results were counterintuitive. As shown in Figure 3, the max temperature in the “vein merge,” in fact, decreased.

Explanations for this finding were that the blood was from a vein that had already passed through tissues and was, therefore, leaving its core temperature heat in the tissues before affecting the surface temperature of the skin. However, this is a post hoc explanation, because the thermal imagery finding was not predicted.

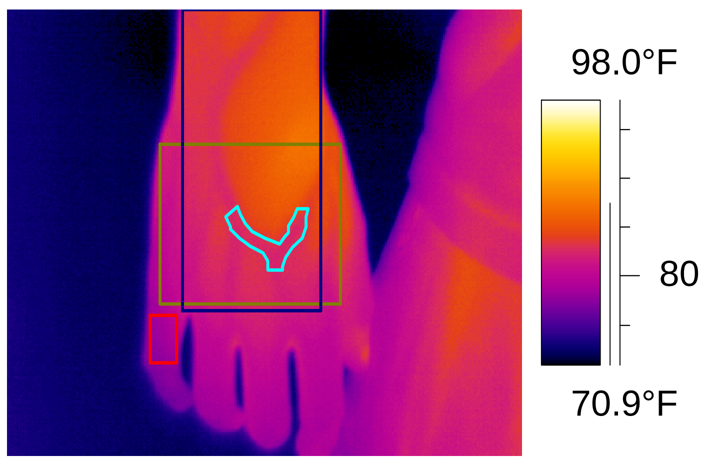


Figure 2. Hand shown in Figure 1 with the segments outlined.

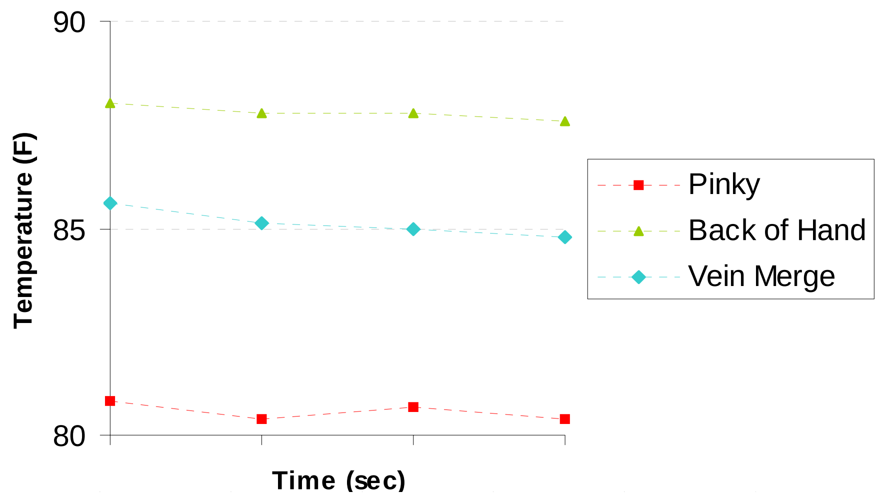


Figure 3. Graph plotting the skin radiometric temperature in the three segmented areas shown in green, blue, and red on Figure 2.

AEROBIC EXERCISE EFFECTS IN THE FACIAL SIGNATURE

During aerobic exercise, energy is generated internally from the mechanical work being produced. Energy storage in the body follows the general energy balance equation:

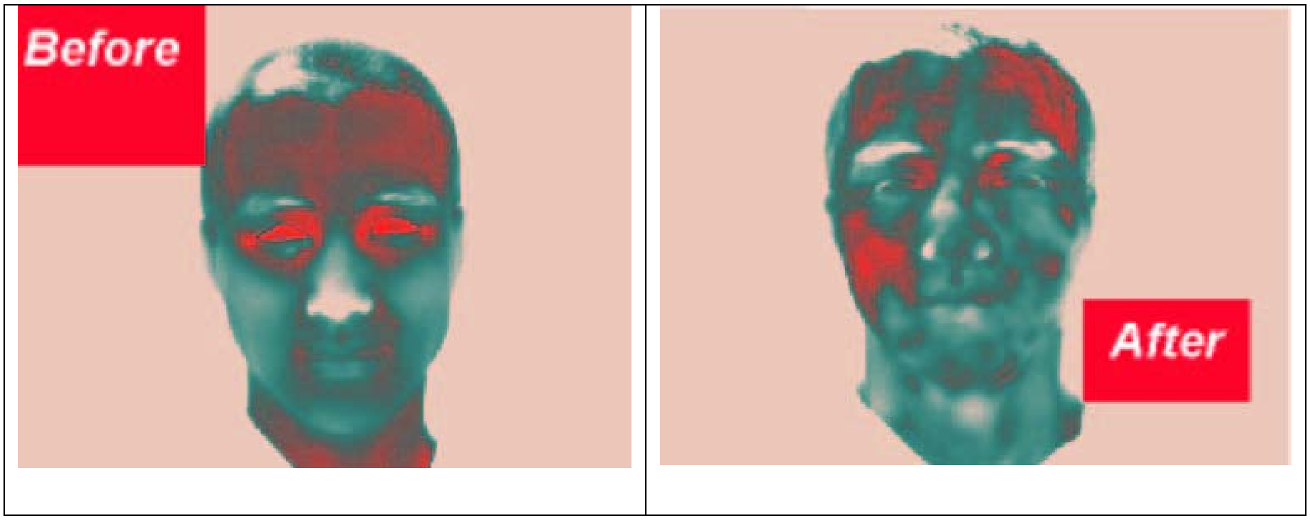
$$S = H - (\pm W) - E \pm R \pm C \qquad \textit{Equation 1}$$

where S = rate of energy storage
H = rate of internal energy production
W = rate of mechanical work produced during exercise
E = evaporation energy loss to air
R = rate of radiation energy loss to the surroundings
C = rate of energy loss by conduction and convection. [2]

The control of body temperature is regulated by the hypothalamus, which senses the temperature of the blood and balances heat generation with heat loss. As described in Jones and Plassman [3]:

A small area in the anterior of the hypothalamus detects an increase in blood temperature and sends neuronal signals to activate methods of heat loss such as vasodilatation, perspiration, exhalation, and a reduction in the metabolic rate….The skin is heated by thermal conduction from blood vessels, and vasodilatation allows increased thermal conduction and radiation, though these are not large effects… Perspiration in the presence of forced convection is the most effective way of losing heat. A small area in the posterior of the hypothalamus detects a decrease in blood temperature and may reduce heat loss by initiating vasoconstriction and goose pimples when the hair rises and traps an insulating layer of air. Heat may be generated by muscular activity such as shivering.

To explore how the thermal imagery would look when people are internally generating heat through intense aerobic exercise, people were imaged before and after running/jogging for 2 miles. A typical general result is shown in Figure 4. In all cases the facial signature looked relatively smooth before the aerobic exercise and then mottled and splotchy afterwards. This effect appeared to disappear within 15 minutes after the cessation of exercise.



1.

Figure 4. Example of before and after aerobic exercise (jogging) shown in greyred palette (red = hot). Note that the smooth appearance of the skin is relatively gone in the "after" photo, which has a mottled appearance.

1.

In another session, a person was thermally captured while riding an exercise bicycle for 35 minutes, being wiped down, and then during 15 minutes of cool-down (very slow or no riding). Images were captured with the ThermaCAM SC 1000 (in the 3-5 micron band) as a profile every 5 minutes. The images before beginning to ride and after each 5-minute period of bike riding are shown in Figures 5a-5h. After 35 minutes, the sweat was wiped off the rider's face with a towel. Figure 5i shows that the signature was virtually unchanged by removing the actual sweat itself from the face. The signature does not even appear smudged.

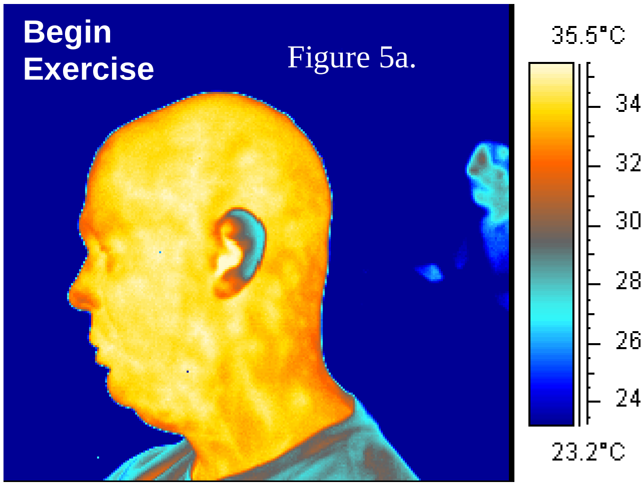


Figure 5a.

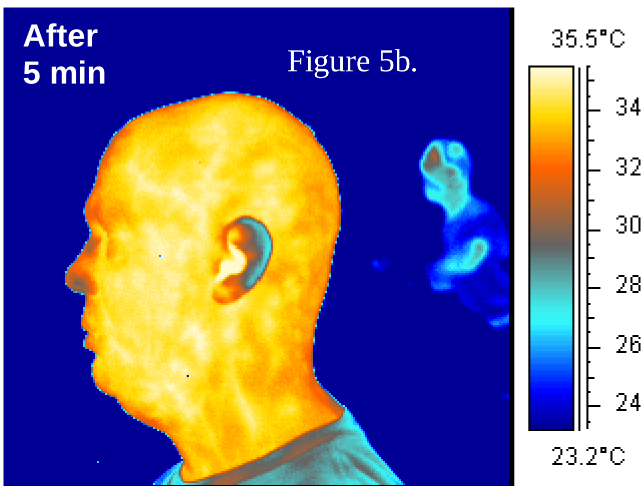


Figure 5b.

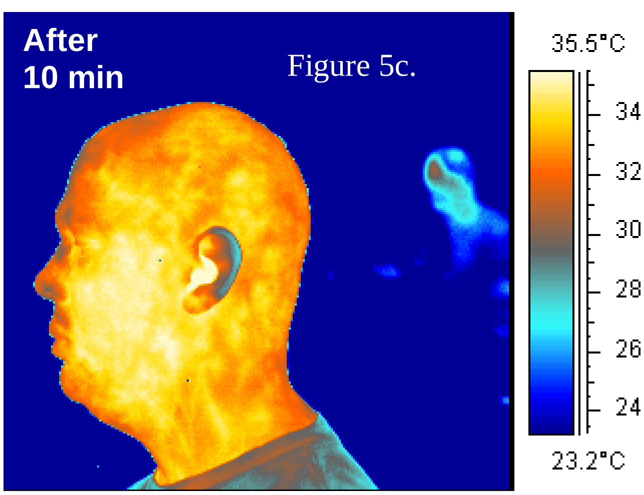


Figure 5c.

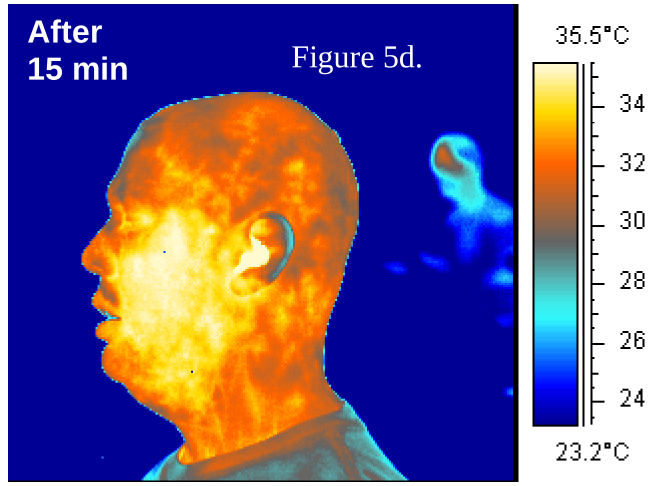


Figure 5d.

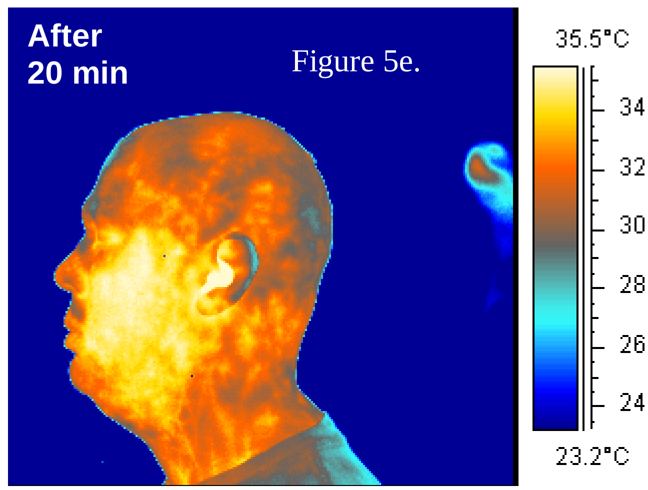


Figure 5e.

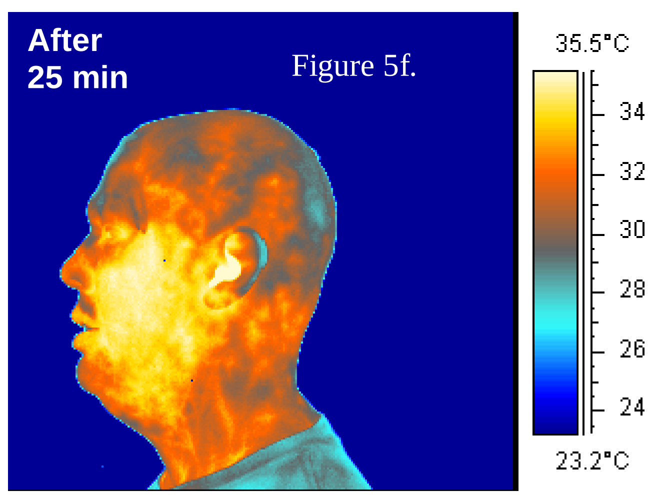


Figure 5f.

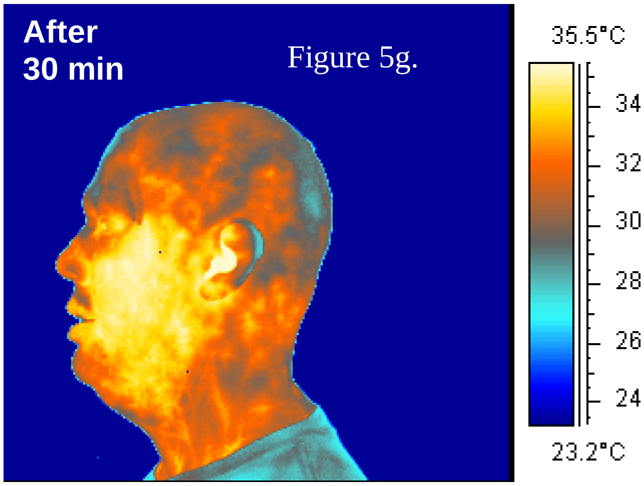


Figure 5g.

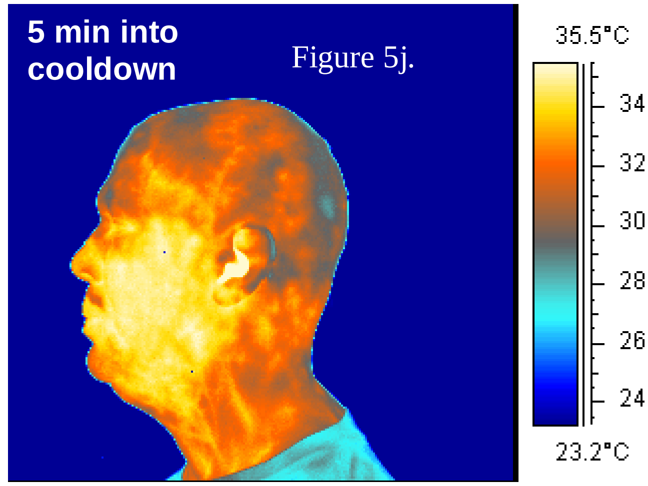


Figure 5j.

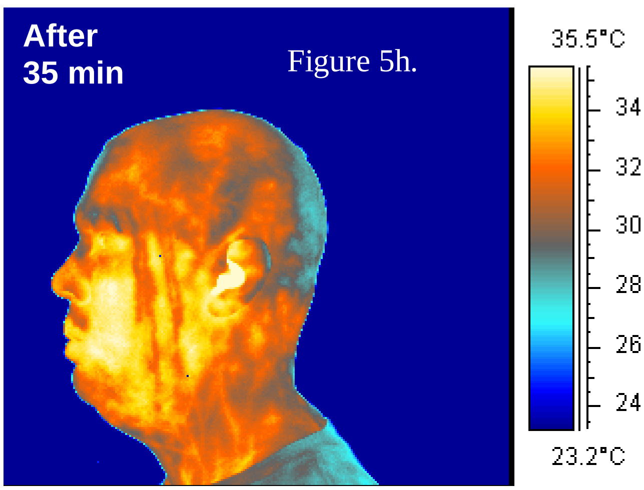


Figure 5h.

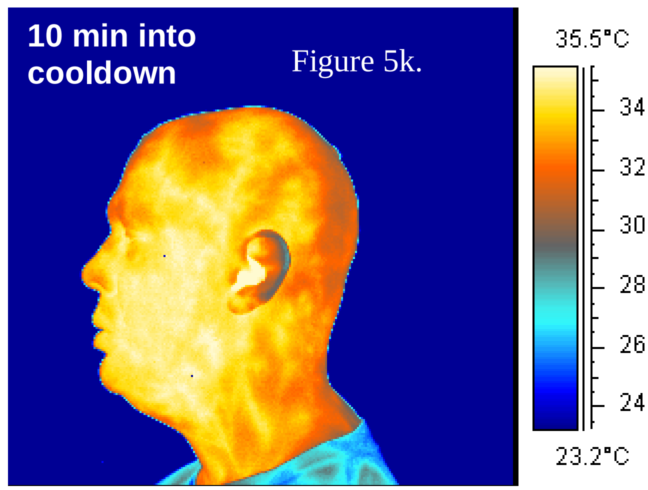


Figure 5k.

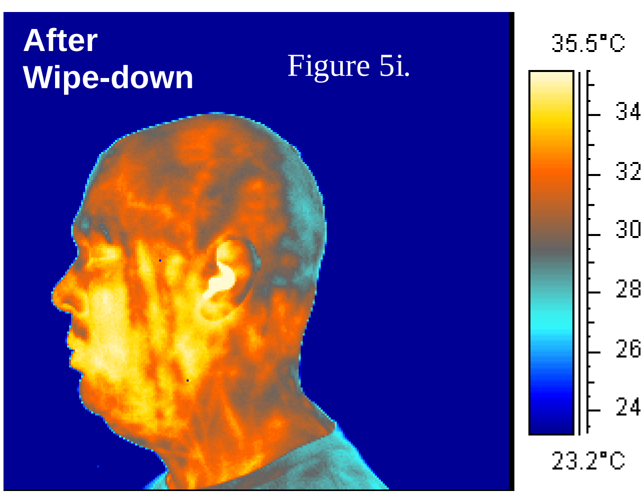


Figure 5i.

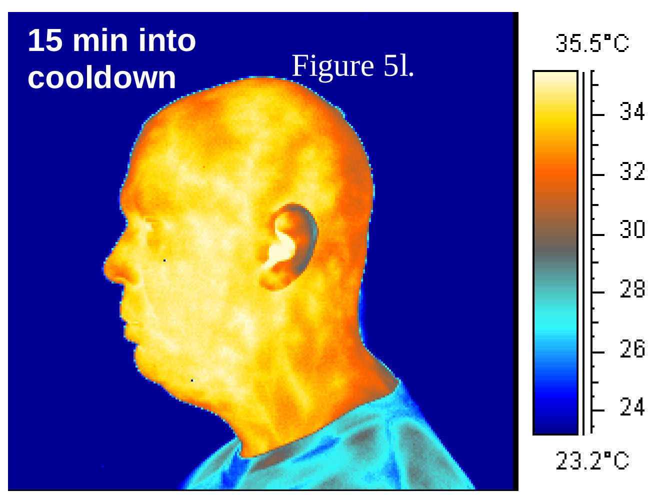


Figure 5l.

Figure 5m.

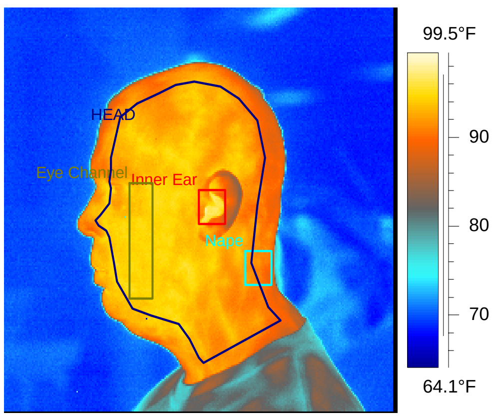


Figure 5n.

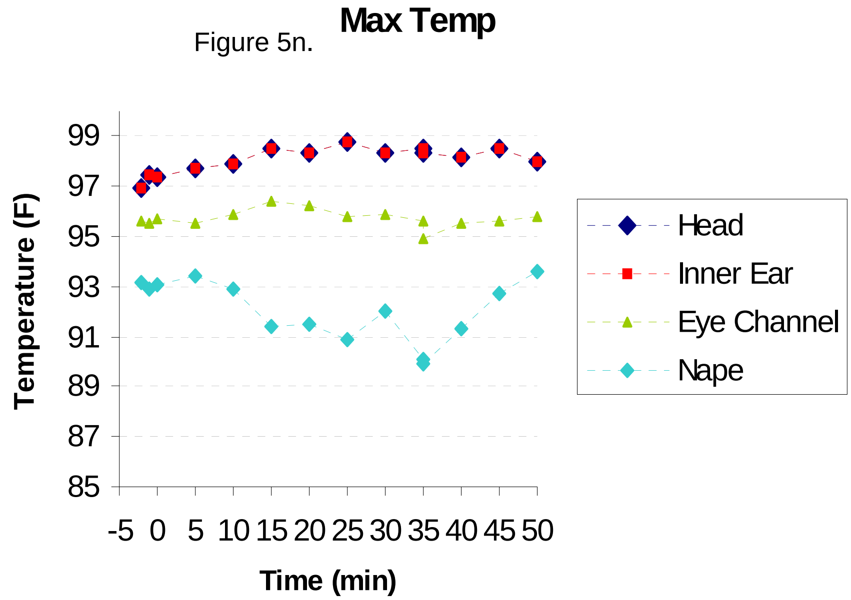


*Figure 5. Figures **5**a-**5**l show **thermal imagery taken** before, during**,** and after exercise **using** a 3-5 micron camera, **the ThermaCAM** SC 1000. Figure 5m shows the segments of the head analyzed, **while** figure 5n shows the graphic of the maximum radiometric temperature in the segmented regions.*

During Exercise	**Max**	**Min**	**Avg**	**StDev**
Head	↑		↓	↑
Inner Ear	↑	↑	↑	↓
Eye Channel	↑	↓	↓	↑
Nape	↓	↓	↓	↑

During Cooldown	**Max**	**Min**	**Avg**	**StDev**
Head	↓		↑	↓
Inner Ear	↓	↓	↓	↑
Eye Channel	↓	↑	↑	↓
Nape	↑	↑	↑	↓

Figure 6. Trends for the maximum, minimum, average, and standard deviation of the segmented areas of the head and neck during the exercise event and during cool-down time.

The face was segmented as shown in Figure 5m, and the statistics were calculated for each of the four areas: head; ear; “eye channel,” where the sweat was seen to be running down; and the nape of the neck. The inner ear was the hottest part of the head and, therefore, rose in temperature, whereas the nape of the neck was the coldest part and decreased in temperature during the exercise. At cool-down, the process reversed, with the inner ear cooling down and the nape of the neck warming up to its pre-exercise radiometric state. The graphic in Figure 6 shows the rise and fall of the statistics of the head and neck during and after exercise. The results show the rise in internal temperature at the inner ear as the mechanical work is produced and the loss of heat (cooling) on the skin surface to reduce the temperature of the blood.

Whereas it might be expected that heat loss would produce the appearance of heat, it seems that heat loss from the body produces an appearance of coolness. This is the reason that simple predictions about the appearance of the body during various activities are not necessarily accurate.

What appears to be occurring in the case of aerobic exercise here is that the radiometric temperature being imaged by the camera is showing that parts of the face are now moistened, forcing the heat into the water molecules. They are thus not available radiometrically; since the thermal camera cannot see the heat once it is no longer radiating but is instead transferred to the air in the form of convection.

Long-wave imagery was taken simultaneously in 20Hz frame rate from the front. Figure 7 shows an image on the left at the commencement of the bike riding and on the right after approximately 30 minutes of bike riding. In the complete sequence of frames, it is possible to see the eyes moving, the nose inspiring and expiring air, as well as the skin becoming cooler.

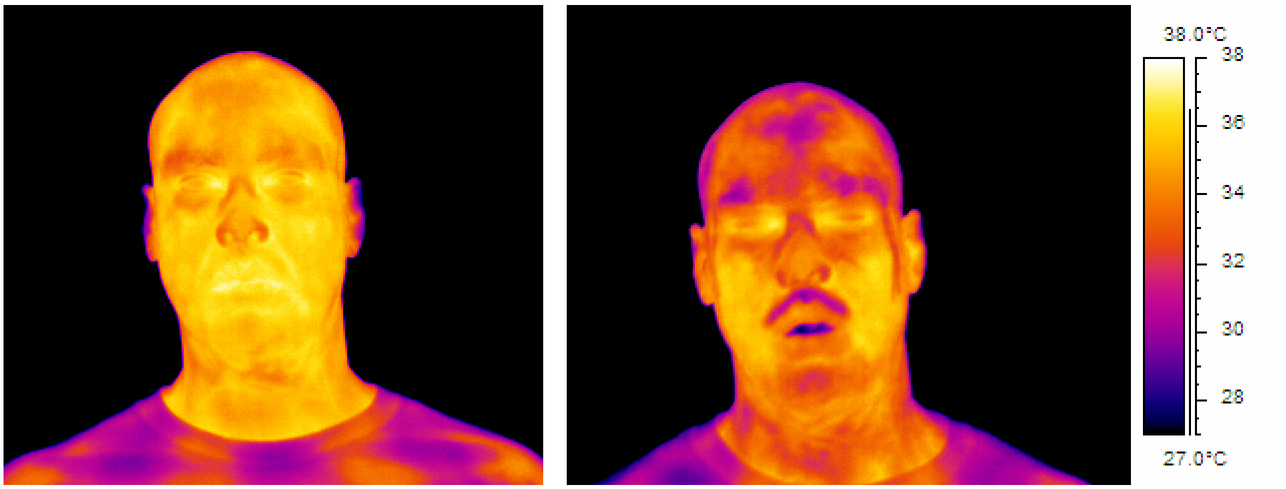


*Figure 7. Long-wave IR views **taken** before and after 30 minutes of stationary bike riding.*

BREATHING

The nostril tends to be visible as a cool spot. With the inspiration of breath, the nostril cool spot becomes noticeably larger and then smaller with expiration. It would be fairly straightforward to count breaths or calculate breathing rates with an automatic algorithm. This could be interesting for the understanding of the person's respiration status, as it relates to his emotional or physical health.

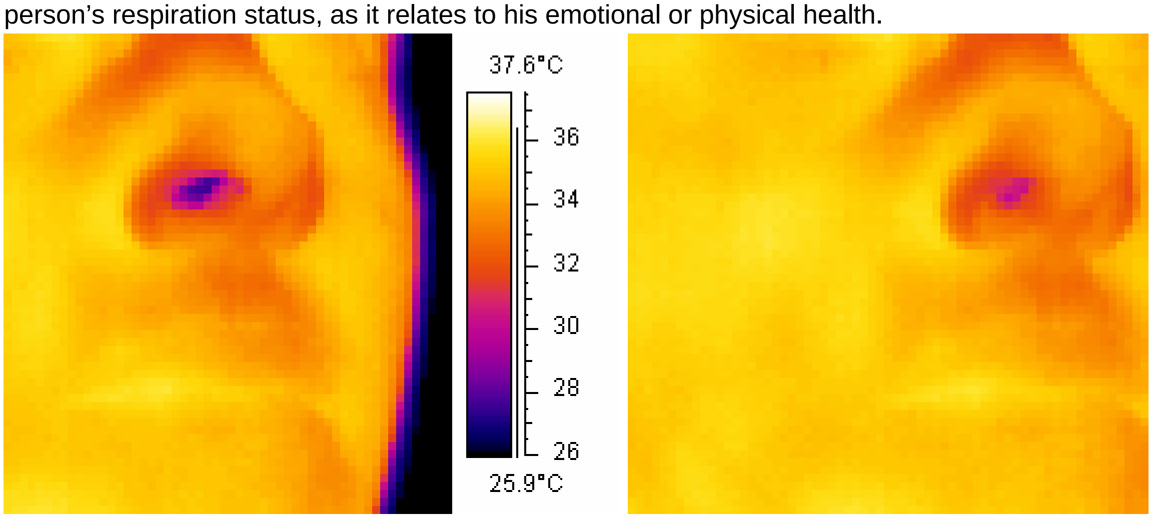
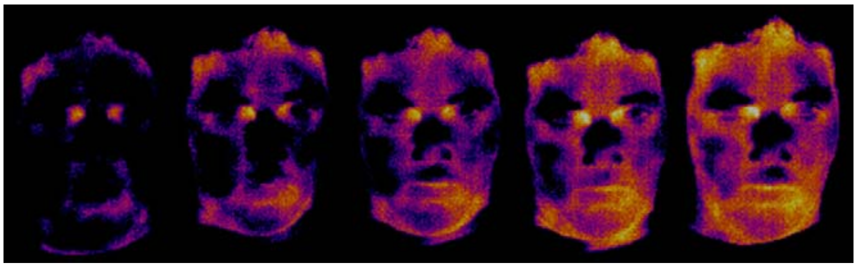


Figure 8. Breathing in (left) and out (right).

PLAYING AGGRESSIVE VIDEO GAMES

Two individuals were imaged while playing an aggressive video game. The results for one individual are shown in Figure 9. As can be seen, the average temperature rose during the course of the playing. This situation represented the only time that the skin was seen to become warmer over time.



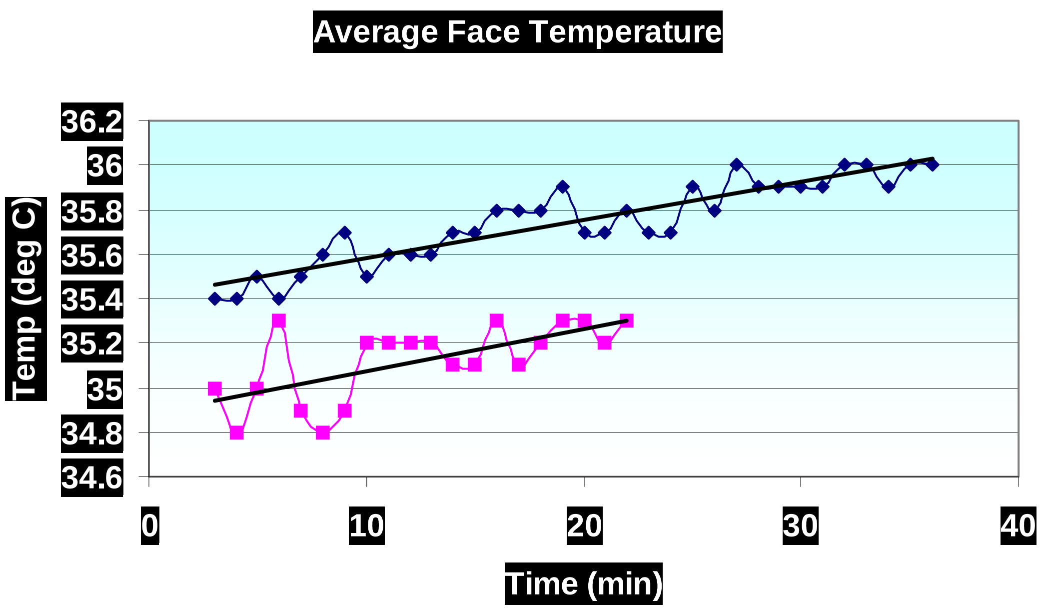


Figure 9. Thermal imagery of two young individuals was taken over 35 minutes, while they were playing an aggressive video game. Average temperature of the surface of the face in both cases increased over the course of the game, as shown in the graphics.

SUMMARY

This paper has shown some very noticeable changes in the thermal signature of the human face during various activities. It has demonstrated the very interesting line of study of the human as a thermal emitter. Others have written about the human face during various contrived emotions, such as guilt, fear, and lying (Levine, et al. [4], Pavlidis, et al. [5], Pollina and Ryan [6]), but the present paper has a more general message about the dynamic changes during everyday life. It represents a kind of natural history of the human thermal signature.

In the medical community, the Association of Thermology and others have done quite a few studies over the years for understanding the thermal signature in disease states and during their alleviation (e.g., Lance and

Anthony [7], Govindan [8, 9, 10], Swerdlow and Dieter [11]). However, the present study looks at the signature in the dynamics of the normal functions of the body (breathing, muscle tension, aerobic exercise, and during aggressive play). The goal is to find the robust patterns, spots, or dynamic changes that indicate underlying internal states.

REFERENCES

[1] O'Kane, B., J. O'Connor, and D. Bonzo. 1998. "Strategy for combat vehicle thermal recognition training." *Proceedings of the SPIE Conference on Signal Processing, Sensor Fusion, and Target Recognition VII* 3374:204-11.
[2] Merla. 2003. p. 87.
[3] Jones, Plassman. 2003. p. 42.
[4] Levine, J. L., I. Pavlidis, and M. Cooper. 2001. "The face of fear." *Lancet* 357, no. 9270:1757.
[5] Pavlidis, I., N. L. Eberhardt, and J. Levine. 2002. "Human behavior: Seeing through the face of deception." *Nature* 415, no. 6867:35.
[6] Pollina, D. and H. Ryan, Jr. 2002. "The relationship between facial skin temperature reactivity and traditional polygraph measures used in the physiological detection of deception: A preliminary investigation." *Department of Defense Polygraph Institute Research Division Report* No. DODPI02-R-0007.
[7] Lance, J. W. and M. Anthony. 1971. "Thermographic studies in vascular headache." *Medical Journal of Australia*:240-43.
[8] Govindan, S. 1990. "Thermography in sleep apnea." *Sleep Research* 19:231.
[9] Govindan, S. 2000. "Monitoring cold patch in clinical practice – An update." *Thermology International*, 10, no. 3:140-1.
[10] Govindan, S. 2001. "Imaging extracranial trigeminovascular system in chronic pain." *Thermology International*, 11, no. 2:92-3.
[11] Swerdlow, B., J. N. Dieter. 1986. "The validity of the vascular cold patch in the diagnosis of headache." *Headache Journal* 26, no. 1:22-6.

ACKNOWLEDGEMENTS

The authors wish to thank the Infrared Training Center at FLIR Systems for their great classes and intelligent staff, who answered a lot of questions from our team and provided the great FLIR infrared cameras. The authors would like to thank Dr. James Ratches, chief scientist at Night Vision Lab, for his support of this research.