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Thermograph Measurements of Human Subjects

An Interactive Qualifying Project Report
submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
and prepared for
THE UNITED STATES ARMY SOLDIER SYSTEMS CENTER
NATICK, MASSACHUSETTS
in partial fulfillment of the requirements for the
Degree of Bachelor of Science
by

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04 March 2004

Approved:

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-:- Abstract -:-

The "Objective Force Warrior," the future of the United States Army, will revolutionize the military. To achieve this, many different pieces of an intricate puzzle must be analyzed. Prepared for the U.S. Soldier Center at Natick Labs, the goal of this project was to determine the thermal response of exposed skin and the effects due to change in temperature and environmental conditions using a thermal imager. The results will be used for camouflage and micro-climate systems research of the OFW.

-:- Table of Contents -:-

-:- Figures, Tables and Images -:-

-:- Introduction -:-

The future soldiers in the United States Army will clearly be the best equipped in the world. In May of 2001, the U.S. Army released information on the "Objective Force Warrior" (OFW), the soldier of the future who will be well furnished head to toe with individual protection, netted communications, soldier worn power sources, and enhanced human performance aids.

In transforming to the Objective Force, the Army has embarked on a major science and technology program which will develop, demonstrate, and field these revolutionary systems. The U.S. Army Soldier Systems Center at Natick Labs, Natick, Massachusetts, has been charged by the Army with developing the OFW. It is not a single system, but rather a system of systems which provide revolutionary capabilities to the individual solder and the small units they are in. The Army's greatest asset, after all, is the individual.

The Objective Force Warrior system will include a built in "microclimate conditioning system" which will act like a private air conditioner, or heater, to the soldier. This system has a "spacer fabric" which is similar to a regular cotton t-shirt and has capillaries that will blow hot or cold air through the system as a whole.

A main concern when designing the system for the Objective Force Warrior is the load carried by soldiers. Currently, soldiers in infantry platoon and combat patrols carry 92-105 pounds of equipment that is essential to their mission. Ammunition withstanding, cold weather and chemical protective gear are a large percentage of the overall weight load. The OFW system will require the soldier to carry no more then 45 to 50 pounds. Extra equipment will no longer be needed with the system's many built in functions, but it is the innovative climate-control feature which will eliminate unnecessary clothing to be carried. The outer shell will also include chemical and biological protection capabilities.

In the past, researchers have upgraded the current equipment. The OFW program put a stop to this rationale and designed from the skin out, literally. With these new advances in technology, up to date and accurate databases are also required.

Human skin is much different from soldier to soldier, and the variables concerning temperature and adaptation to the thermal environment are important ones to consider when designing both the outer and inner shells of the OFW. Until recently, temperature measurements of the human skin were done with bulky, prototype machines with little or no reliability. That is not the case today, where thermal imaging is not only used in the military, but even becoming commonplace in hospitals and fire stations across the country. With the push of a button, temperatures and their deviations can be taken to one tenth of a degree. To say that the current thermal imagers on the market are accurate would be an understatement.

Working at the Army Soldier Center in Natick, I used an Inframetrics Model 760 IR Imaging Radiometer, or a thermal imager. Pooling from a variety of human test subjects, a database of temperature features and deviations of the face, neck and hands was compiled. Also tested and recorded were the subject's core body temperature and the temperature emitted from what is essentially the soldier's outer shell, the battle dress uniform.

The said test subjects were made up of a variety of different skin tones, facial features and ages. Soldiers in the military are after all, not the same. For example, a lighter skinned person has a 3-4 degree temperature differential when exposed to the elements then a fair skinned person has. This is just one of many findings listed in this new and up to date database on human skin temperatures.

There is a fine line in the balance of a soldier's heat production and the exchanges of heat through the surroundings and environmental conditions. Even when this balance is achieved, however, the individual may not be in "thermal comfort". There are narrow intervals of skin temperature and the production of sweat, and these intervals are even smaller when the variable of face paint, or camouflage, is introduced to the human skin.

"Thermograph Measurements of Human Subjects" is just a small piece in the intricate puzzle of the Objective Force Warrior, but still key in the knowledge and understanding of the human body and its largest organ, skin. As new technologies become available and practical, the future warrior is closer and closer to being the warrior of the present. The system is scheduled to be tested in the field in the 2010-2012 timeline.

-:- Background Information -:-

This literature review is meant to provide supplementary material that is relevant to the direction of the project. Included is information about thermal imagers and their applications, and skin research. The topics to be discussed in the background information include:

- history of thermography
- infrared thermography
- thermography in medicine
- skin temperatures
- skin in cold and hot environments
- civil and industrial applications of thermal imagers
- flame exposure
- military applications

2.1 The History of Thermography

The detection of body warmth has a profound impact on humans. Even primitive humans knew that warmth was associated with life, and the body of a dead person was cold. Thermography is the study of biothermal processes to assess heath and disease. Moderate body temperature and health go hand in hand, as do high body temperature and disease.

The history of thermography can be traced back to the days of the ancient Egyptians. Although they did not have infrared cameras or thermometers, the Egyptians used the scanning capability of their fingers to interpret the surface temperature of the body. By reporting the increase or lack there of, of temperature, these ancient doctors and scientists could determine if a specific wound was localized or spread through the body as a whole.

As time went on, it was realized heat played an important role in nature, and good health was perceived as a balance between the 'elements'. The assessment of body temperature became an integral part of Greek medicine (600-400 BC). The Greek Physician, Hippocrates (460-377 BC), wrote "In whatever part of the body excess of heat or cold is felt, the disease is there to be discovered." In Hippocrates' textbook *The Book of Prognostics*, he underlined the importance of assessing the temperature of the hands, feet, cheeks, lips and ears of patients. Although use of the hand to measure skin temperature was still commonplace, the ancient Greeks would immerse a body in wet mud, and determine that the area drying the quickest, indicating a warmer region of the body, would be considered diseased tissue.

About 600 years after Hippocrates, Galen (130-210 AD) conceived the notion that body heat is produced by the biocombustion of food. Galen also advanced the theory of sensory and motor nerves, which is the primary variable of thermoregulation.

Although ancient civilizations could quantify weight, volume and distance, temperature was ever measured until 1592, when Galileo Galilei (1564-1642) invented the first semi quantitative air thermometer. This was known at the time as Galileo's 'thermoscope'. The importance of this innovation was the fact that *changes* in temperature could be observed and measured.

Adding on to Galileo's invention, Santorio Sanctorius (1561-1636), a friend of Galileo, developed the first thermometer. In 1611 he marked 110 intervals on a glass tube of water. One end of this tube was immersed in ice water, the other placed near a burning candle.

The first actual images of temperature were made possible by the use of liquid crystals. Cholesteric esters have the unique property of changing color with temperature increase or decrease. By applying these crystals to the surface of this skin in the form of panels, a visual image of the temperature would result. This was extremely inaccurate, however, due to that fact that any physical contact with the skin can change the temperature dramatically.

In 1800, Sir William Herschel (1738-1822), in Bath, England, discovered the first existence of infrared radiation. By trying to measure the heat of separate colors in the rainbow spectrum, he found the highest temperature to fall beyond the red end of the spectrum. Sir John Herschel (1792-1871), his son, was interested in photography, and recorded the heating rays on the infrared side of red by using carbon suspension in alcohol.

He called this image a ‘thermogram’. This was the foundation that would eventually advance to sophisticated thermal imaging devices over one century later.

2.1.1 Temperature Measurement

Today’s thermal imagers are an excellent way of determining the temperature of a surface. Although thermal imagers are revolutionary, there are still many variables involved that must be precisely monitored. Thermal imagers measure radiation, and the radiation received from the object (i.e. human skin) is a function of the temperature, emissivity, reflections from the surroundings, atmospheric transmission, and the transmission from the object through the imager’s optics (Burnay, 20). Finally, specifically in this project, imagers are transmitted from hard disk to computer software for further analysis.

It is necessary for database measurements to be made in a temperature-controlled environment with time allowed for subjects to reach thermal equilibrium with the surroundings.

2.2 Infrared Telethermography

The thermal imager, in its simplest form, consists of a lens that measures the thermal radiation from a scene on to a heat-sensitive surface. This surface is displayed so it’s visible to the naked eye. Radiative heat was first studied by Sir Isaac Newton (1642-1727). Newton formulated that any object which is warmer then its environment would dissipate excessive heat either by contact with materials in the environment, or by emitting radiation. In simple terms, the difference between light and heat radiation is that we cannot see heat radiation with our eyes the way we see light. This is because the human visible spectrum ends with radiation perceived by us as red. Heat radiation is infrared, or 'below red'.

It has also been known that objects become very hot when they start to radiate. Beginning with red, the object will turn yellow when hotter, eventually becoming 'white hot", a term used frequently in conjunction with thermal imagers. In 1899 Max Planck (1858-1947) hypothesized that emitted energy is quantized. This is to say that as energy increases, there are fewer states that can emit electromagnetic radiation. Planck's universal constant, well known in physics, was determined.

Planck used his knowledge to calculate blackbody fluxes of energy for any temperature, and thus determined temperature by measuring the radiation emitted. Human skin temperature, which is normally 86-96°F, is located in the infrared part of the spectrum.

2.3 Thermography in Medicine

Thermography plays its most important role in medicine, where many uses of thermal imagers and infrared technology are now commonplace. Included in the many types of treatment and prevention are:

1) The assessment of inflammatory conditions
2) The assessment of pain and trauma
3) Vascular disorder investigations
4) Oncological disorders

Inflammatory conditions often provide tissue with swelling, giving areas of the skin a higher temperature then normal. Thermography is a useful tool in distinguishing arthritis from common injuries. Arthritis will provide a well defined circular pattern of increased heat over joints, whereas warm areas in superficial vessels will be sporadic and elongated.

Thermography is also used in the recovery of inflammatory states, with or without the use of drugs. Minor changes in joint temperature can easily be monitored, along with the effects of drug and physical therapy (Burnay, 45).

Patients with vascular disorders typically have cold and very poorly circulating extremities, the hands in particular. By putting a patient's hands in a hot or cold stress environment, thermal recovery of the skin, monitored by thermal imagers, can easily tell physicians if particular patients have decreased blood flow. Again, a thermal imager can monitor the effect of drugs, if issued, on the patient.

In more severe cases, tissue damage with cool skin but adequate blood flow in the major vessels can be analyzed. In many cases arterial disease is present when these symptoms are found. Chemical sympathecotomy, which increases the flow of blood through vessels, is often the solution.

Temperature increases have also been found to occur over tumors. The thermal pattern over skin lesions is usually localized in a small section over the tumor. Temperature increments of 3-5°F have been measured over known tumors on the leg, thigh, abdomen and face.

2.3.1 Breast Thermography

More recently, breast thermography was introduced as a diagnostic procedure that aids in the early detection of breast cancer. Chemical and blood vessel activity in pre-cancerous tissue and the area around the breast, is always found to be higher then that of a normal, non-cancerous breast. Cancerous tissues are highly metabolic, meaning they need an abundant supply of nutrients, or blood, to maintain a steady growth. Unlike some forms of detecting breast cancer, the use of a thermal imager is both safe and comfortable for the patient. Thermal imagers also provide the earliest signs possible of pre- cancerous activity. It has been found that in conjunction with clinical examinations, thermography can detect 95% of early stage cancers.

2.4 Influencing Factors in Skin Temperature

There are many variables that influence skin temperature. There are also considerable individual variations in the temperatures found on the skin surface. These are all dependant on skin and fat thickness, and overall blood flow status. Those are in turn, dependent on a number of factors.

2.4.1 Age

Age is one of the most important factors in determination of skin temperature. The warmth of a newborn baby is one of the first things a mother notices. Studies have shown that the skin temperature immediately after birth is uniform throughout the whole body, but is significantly lower at the core temperature. Soon after birth, skin temperature becomes cooler and core temperature rises. As a child gets older, a more structured pattern of temperature is developed throughout the body.

As humans age, especially into their 80's, skin temperature does not change, rather the pattern of skin temperature does. In the first half of life, a 'V' shape is represented on the back of both males and females (Mount, 35). This is to say the hottest spots on one's back are in the middle. The neck area is part of this ‘V’ shape. As age progresses, the ‘V’ turns into a ‘T’. Skin surface temperature increases around the neck and shoulders, and decreases near the lower back.

2.4.2. Obesity

Fat is an excellent insulator, and in obese people it changes the temperature distribution immensely. Heat is transferred by direct conduction, and together with the altered blood flow of someone overweight, different thermal patterns are produced. Fatty areas have an expected increase in skin temperature, but the largest increase occurs in skin above the spine. Because the spine is supporting a larger load, blood flow increases, and in turn raises the skin temperature.

2.4.3 Exercise

Any exercise must be considered when analyzing thermal patterns. For example, while running, considerable heat is produced by the active muscles in the legs. Exercise in turn increases the core temperature, but leaves the subject will no ill effects. The exchange of heat energy through the skin surface into the environment is what allows soldiers or athletes to perform without core temperatures reaching dangerous levels.

Warm skin over active muscles is a notable feature. The most important factor to consider when studying skin temperature in conjunction with exercise, is the redistribution of blood flow to the active muscles and away from other skin areas. This can best be observed during exercise of the abdomen. When normal sit-ups are executed, the temperature of skin directly above the abdominal muscles themselves increases dramatically, but skin only a few inches away on the side of the stomach will only have a moderate increase.

2.4.4 Environmental Conditions

Environmental conditions can have an astounding effect on skin temperature. As the environmental temperature increases, there is a smaller gradient between the temperatures of the skin and that of the air. Sweating, and the evaporation of sweat, is the main cause of heat loss with the change of environmental conditions (Mount 102). This is to say that skin temperature becomes much more uniform with the increase or decrease of air temperature. Cold and hot environments are discussed more in Section 2.5.

Subjects with facial hair adhere to this principal even more soundly. Hair is a passive material, meaning it simply takes the temperature of its surroundings because it has no mechanism for temperature change. In hot air, hair will become one of the warmest areas of the body, and in cold air, one of the coolest.

2.5 Human Skin in a Cold Environment

Skin temperature is particularly susceptible to air movement, or wind. Skin exposure to wind at low temperatures greatly increases the cold effect, producing what we call wind chill. When the face in particular is exposed to wind at low temperatures, decreases in skin temperature vary within different parts of the face. For example the sensation of cold is much more pronounced on the nose and cheek then it is on the forehead.

Although chilling effect of the core temperature has a direct correlation to the level of insulation in one's clothing, the face and hands are sometimes unavoidably exposed to the elements. For example, high air velocities, like that of a soldier standing below a hovering helicopter, can lead to pronounced cooling. These air velocities leave an unprotected area such as the face with major heat loss, which can account for up to 40% of total body heat lost.

2.5.1 Injuries Induced by Cold

Frostbite is the most severe and common form of local cold injury to the skin. At extremely low temperatures, circulation of the skin decreases, and death of the tissue can occur. Frostbite has occurred extensively in past military campaigns where large numbers of soldiers have been placed in conditions where extreme cold is present. Frostbite is becoming less of an issue, as modern clothing and proper insulation are very efficient in preventing this hazard.

2.6 Human Skin in a Hot Environment

Man's tolerance of heat is a large contrast to that of cold. This is caused by the ability of man to produce sweat at a high rate. If a soldier lives in a hot environment, such as the desert, and has adequately adapted, equilibrium with the environment will cause the skin to become very stable at hot temperatures. If one is not properly adjusted to the heat, the body changes in many ways and sickness can occur. The fall of core body temperature, a decrease in the heat rate and an increase in sweating are three physical changes one can expect if not properly acclimated.

2.6.1 Sweating

The body's response to heat is sweat. Sweat's main function is to provide the body with thermo-regularity throughout. In a cool environment, evaporative heat loss can account for 25% of the heat produced by a man who is not exercising. As the air temperature rises, this sweating will account for total heat loss. As a result, human skin can withstand very high temperatures, even at a dry atmosphere, due to the essential sweating function of the body.

2.6.2 Thermal Comfort

Narrow intervals of skin temperature and rates of sweating correlate to thermal comfort. With skin temperatures between 89 - 95°F, there is little to no sensation of warmth or cold in a subject with normal blood flow and no vascular disease. The maximum temperature for thermal comfort is said to be 91°F.

Feelings about skin temperature can be affected by core temperature. For example a subject at normal core temperature would find being submerged in water at 60°F to be a pleasant experience. A subject who has gone into hypothermia, however, would find 50 degree water to be unpleasant, to say the least. Visa versa, water at 100°F would be uncomfortable to the normal man, but pleasant to one who is hypothermic.

2.7 Other Applications of Thermography in Medicine

There are literally hundreds of applications for a thermal imager in twenty-first century medicine. Although this paper has discussed some of the major uses in detail, it is important to note a few of the other.

We all know that cigarette smoking is hazardous to your health, but cancer and emphysema are just some of the problems associated with it. With the use of a thermal imager, physicians can monitor the blood flow rate throughout the body before and after smoking cigarettes. It has been shown that after just one cigarette, the blood flow in a subjects hand reduces dramatically, and the temperature decreases up to 5° F.

Thermal imaging has also been used in cases of third degree burns. Using enhanced thermography, burns can not only be treated more efficiently, but we can also assess the damage of skin blood vessels.

Thermal imaging has also been quite successful in the field of veterinary medicine. Animals of course can't communicate where specific pain resides, but by taking images, much of the guesswork is eliminated and a precise heat map of affected areas due to tissue damage or muscle strain can be analyzed.

Recently, thermal images have been used in conjunction with acupuncture to research paralysis in all areas of the body. Because of the high level of nerves damaged, it is hoped that a link between heat patterns and paralysis can be found.

One thing is becoming clear as researchers continue to use thermal images and thermography in the study of medicine; this is a technology that will provide insight and understanding of the human body more so then ever before.

2.8 Civil and Industrial Applications of Thermography

A thermal imager's primary function is to provide information about temperature differences in a scene, not just the temperature of a subject. Like thermography in medicine, the number of applications in industry is numerous. Thermal imaging has been used in the electricity and building industries, the measurement of stresses in various structures, and the evaluation of composite materials, just to name a few.

2.8.1 Detection of Gas Leaks

Although quite complex, the absorption of infrared radiation, by gases in particular, can be used to detect leaks in industrial systems. Because gas absorbs more radiation from the background then normal air does, a thermal imager can easily detect these leaks, assuming the background has a constant emissivity.

Most situations of gas leaks will not come to the detection of radiation, however. A temperature difference will likely exist due to the fact that the gas is originating from a high pressure pipe.

2.8.2 Electronics

Electronics play a major role in almost every current industry. Not only are most consumer products electronic, but many industrial processes require electronic control, and hardly a home exists in America without a personal computer. The temperature at which electronics run is a direct influence on their life and reliability. Not only must the internal temperature of electronics not exceed a certain level, but because electronics are affected by the temperature of their environment, heat must be concealed within the device as much as possible. Thermal imagers are very important in the development of these electronics to ensure an efficient and long life span.

2.8.3 Oil Pollution Control

Atop an aircraft, oil spills in water are extremely visible with the aid of a thermal imager. Oil has a lower emissivity then water, and as a result clear distinctions can be made. Not only does the emissivity of each liquid play an important role, the reflectivity of oil in relation to water produces different reflections and radiations from the sky. Thermal imagers are so sensitive to emissivity, that a .01mm oil thickness can be visible.

2.8.4 Insulation and Windows

Thermography is an excellent way to inspect proper insulation of houses and windows. Inspecting the insulation of a house is as easy as taking at thermal imager on a cold day and photographing the ceilings and walls. The smallest temperature deviation will appear, and the house can then be properly insulated.

Thermography can also be used to detect defects in windows such as hot spots and breaks in the glass. Although this is primarily used in car manufacturing plants for auto glass, thermal imagers have also been used to inspect the glass and de-icing systems of aircraft windshields.

2.9 Fire Exposure and Thermal Imaging

The growth of thermography is widespread, but there is no other group that uses thermal imaging more then the nation's firefighters.

The applications of a thermal imager to fight fires are astounding. Extreme areas of heat can be found and quickly ventilated, and windows and doors can easily be identified in zero visibility, allowing firefighters to find entrances and exits. Resources at a fire can be utilized more efficiently by quickly getting water to the fire, not just the smoke. Thermal imagers do not stop once the fire has been put out; soon afterwards hot sports can be located where a fire might reignite.

The most important use of a thermal imager, however, is the ability to find unconscious victims located in a burning house. Instead of blindly groping walls and floors in search of bodies, a thermal imager can quickly let firefighters know where people are located.

The battle of fighting forest fires is also made easier by thermal imagers. An imager is usually mounted on fire towers or high ground to detect fires and hot spots.

Although thermal imagers were first used to see through smoke, they have now provided firefighters with valuable, time saving information that has saved many lives.

2.10 Military Applications

There is no denying the effect thermography has on the military's ability to fight battles and win wars. Apache helicopters are being equipped with forward looking infrared units to give the pilot a thermal picture miles ahead of the aircraft. Fighter jets, such as the F-16 and the Tomcat, use thermal imaging to locate specific targets from long distances. Thermal imagers even play a major role in weapons, such as the heat seeking missile which is guided with infrared technology (Gourley).

Closer to the ground, thermal imagers come in many different configurations to suit specific needs. Amour tanks have infrared systems aboard that allow navigation of any terrain day or night. Snipers are even furnished with thermal infrared imaging weapon sights which can easily identify and acquire living targets from distances like never before. Even ground forces are being issued pocket sized thermal imagers for short to medium range surveillance. Not only will squads be able to see through smoke and dust on the battlefield, but reconnaissance and navigation will benefit during the day, and especially at night.

The methodology section of this report will focus on how the results of this study will be obtained. The numerous variables involved in thermal imaging must be understood and limited as much as possible to provide accurate data.

3.1 Functions of the Thermal Imager

Before any measurements can be taken, the thermal imaging device must be studied. The thermal imager is after all, a computer system. This particular system is quite advanced, but like all computers, will not perform any action it is not instructed to. We must fully understand the abilities, and limitations, of this machine. A well rounded knowledge of the different functions of this device will directly affect the accuracy of our database.

As previously noted, the machine used in this study is an Inframetrics Model 760 IR Imaging Radiometer, manufactured by FLIR Systems. Appendix B offers more information about this company. This model of imagers features seven primary operating modes and an eighth, auxiliary mode. Using an on screen menu, we can select image, color, point, average, area, isotherm, line or aux modes. We will only use a few of these modes in the acquisition of our data. Although these features are important in recording data, they will not affect the calibration of the system.

3.1.1 Image Mode

After initial power up, the cryocooler inside the machine must reach operating temperature before measurements can begin. Once this is complete, image mode will be immediately selected. The keypad can be used to adjust the field of view parameters. This will be helpful when taking images of faces in particular. Using the center temperature control, the temperature corresponding with the mid-grey intensity level in the image will be increased. This will 'darken' the image, and show detail in the warmer target areas. Rotating the temperature control in the other direction will do the opposite and show detail in colder target areas.

Temperature span keys can also select the full-scale sensitivity of the images. The 'normal' range will allow maximum sensitivity for target temperatures up to 750° F. The 'extended' range will allow imaging of targets up to 2700° F.

3.1.1.1 Freezing an Image

A freeze mode will be used to keep the current image on screen. This will be particularly useful with human subjects, because they will not need to stay in a pose for an extended period of time. As soon as an expectable image is provided, the freeze mode can be enabled, and that image can either be saved to hard disk, or analyzed on screen.

3.1.2 Color mode

The color mode is about aesthetics as much as actual temperature measurement; however the color palate chosen may help determine temperature ranges quicker and more accurately. There are nine color palettes to select from. Each palette contains between six and twenty colors. Table 3-1 shows the different color palettes available.

It is important to note that images can be taken in any color palette, and then modified with different palettes using the ThermaCAM software. More on this software can be found in Section 3.2.

Palette Number	Display
0	10 Color rainbow
1	20 Color Rainbow
2	256 Color Graded Rainbow
3	256 Color Modified Graded Rainbow
4	Ironbow
5	GLObow
6	10 Color Contour with Black Dividers
7	10 Color Medical
8	2 Color plus B/W Saturation Detection

Table 3-1 Color Palate Selection

3.1.3 Point Mode

Point mode gives us the ability to record actual temperature values of a single point on the scene or subject. Vertical and horizontal cursors appear, and point measurements can be taken with these 'crosshairs'. Five seconds will be required for readings to stabilize.

3.1.4 Area Define Modes

The area measurement mode will be used extensively. Using this mode, the average temperature within a rectangular box is obtained. The size of the box, both vertical and horizontal lengths, can be defined. Using this method can give us the average temperature of a body, face, or hands.

3.1.5 Saving Images

Thermal images will easily be saved to a 3.5 inch floppy disk. This disk can be put into any personal computer, and with the appropriate software, the images will be further analyzed. Previously saved images can also be recalled from disk to the imager screen.

3.2 Analysis with ThermaCAM Computer Software

Although the thermal imaging device is the most important tool in this project by far, it is best used in conjunction with computer software. Temperatures can be taken directly from the imager, but the speed and convince of a personal computer will make the project as a whole run smoother. Images can quickly be transferred from the device to a computer, and if any problems have occurred in either the photographing of the image, or the saving of the file, they will be noticed immediately, and the subject can be photographed again soon after.

The software will be able to perform a variety of tasks besides temperature collection. Tables of highlighted fields can be summarized and trends or graphs of temperature deviations can be created. Images can also be cut and paste for direct comparison.

Most importantly, the color palate of images may be changed. The correct color palate will not be determined until after the image has been taken and a quick analysis done. Key data may show up with some palates and not with others. The ability to switch back and forth between palates with this software is very convenient.

3.3 Test Subject Information

It is extremely important that information is reported for each test subject. A template will be made that lists all imperative information and this same template will be used for every subject measured.

Information about the individual subject will include; sex, age, skin tone, core body temperature, and uniform. Although the majority of our subjects will be in the Army battle dress uniform, a number will also be in civilian clothes. We must make sure clothing is considered because it will be a factor in the subject's core body temperature. Skin tone will be measured on a scale of one to five, five being the darkest skinned person.

If the image is to be taken outside, the temperature, sky conditions, brightness level, and wind must be recorded. Indoor readings will include temperature and room brightness. Also recorded will be the distance the subject is from the imager.

Core body temperature will be taken with an ear thermometer, which is accurate to one tenth of a degree.

Logistical information will include the time and date of all images.

3.3.1 Physical Activity

If any physical activity has been performed before the image is to be taken, it must be noted. This includes the simple task of walking for more then five minutes. The slightest activity will raise blood flow, and if done in an enclosed area, dramatically raise skin temperature. All physical activity by each subject will be limited as much as possible.

3.4 Camouflage Testing

By using the thermal imager to take pictures of the face before and after camouflage face paint is applied, and in variable environmental conditions, we will better understand the effects of face paint and body heat.

When applying the camouflage to the face, a two color combination of shades of green will be used. Shiny, or high areas, will be painted with a dark color. These areas of the face include the forehead, cheekbones, nose and chin. The shadow, or low areas, around the eyes, under the nose, and under the chin, will be painted with the lighter shade of green, loam. As in all temperatures and images recorded in this report, the ears will be negligible due to their high temperature curve in relation to the face as a whole.

Images will be taken before and after face paint is applied to determine any heat loss or gain on the skin. A subject will be subjected to cold conditions, preferably air at 32°F or less, and acclimated to the temperature. Acclimation to a proper temperature should occur within ten minutes.

The subject will then be brought inside to a controlled environment, and thermal images immediately taken. Images will continue to be taken every minute until the average face temperature is that of the previous reading before the subject was exposed to the elements.

This experiment will also be done without face paint, and graphs will be provided to determine the acclimation rate of both tests.

-:- Analysis and Conclusions -:-

The purpose of this section is to provide the data researched from thermal images in this project. Analyses will also be provided on certain aspects of thermal imaging, including face paint camouflage application and the effects on skin due to cold temperatures.

Although some projects include separate chapters for results, analysis and conclusions, this particular project is best suited with one section including all of these aspects. Due to the fact the conclusions will lye heavily on graphs and in particular, thermal images, it is best to keep the results and analysis together.

4.1 Skin Temperature Data in the Face

All face temperature data was taken indoors, at 77° F, with approximately 70% humidity. All subjects were acclimated properly to the environment. No physical activity occurred before the image was taken. The distance from face to imager lens was approximately 3 feet.

As previously stated in Section 3.3, a skin tone scale (abbreviated ST) from 1 (light) to 5 (dark) was used in this project. The age of subjects was approximated to generation to determine possible changes in temperature. This was done due to the fact that skin temperature will only vary over the time span of approximately 10 years.

Subject	Description	Average Facial Temperature (F)		Subject	Description	Average Facial Temperature (F)
1	Male	86.2		21	Male	90.3
	40's ST 3				20s ST 2	
2	Male	88.0		22	Male	90.0
	50's ST 2				30s ST 2	
3	Male	88.5		23	Male	89.7
	50's ST 2				20s ST 3	
4	Male	92.3		24	Female	91.2
	30s ST 2				20s ST 3	
5	Male	92.0		25	Female	92.0
	20s ST 2				30s ST 2	
6	Female	86.7		26	Male	89.8
	30s ST 2				20s ST 2	
7	Female	88.5		27	Male	87.8
	30s ST 3				30s ST 3	
8	Female	92.0		28	Male	88.0
	40s ST 2				30s ST 2	
9	Female	92.3		29	Male	89.8
	40s ST 3				30s ST 3	
10	Male	91.6		30	Male	88.9
	30s ST 3				40s ST 3	
11	Male	86.0		31	Female	89.5
	40s ST 3				40s ST 3	
12	Male	90.0		32	Female	86.2
	20s ST 2				40s ST 3	
13	Male	88.9		33	Female	87.0
	20s ST 1				50s ST 2	
14	Male	90.0		34	Female	86.5
	20s ST 2				50s ST 2	
15	Male	91.2		35	Male	88.7
	20s ST 3				40s ST 3	
16	Male	89.5		36	Male	88.9
	20s ST 1				50s ST 3	
17	Female	88.6		37	Female	92.2
	20s ST 3				40s ST 2	
18	Male	88.8		38	Female	91.8
	20s ST 2				40s ST 2	
19	Male	88.0		39	Male	89.7
	20s ST 2				40s ST 3	
20	Male	91.0		40	Male	90.0
	20s ST 4				20s ST 2	

Table 4-1 Subject Description and Skin Temperature on the Face

Image data was obtained using computer software, with a RAIN900 color palate. Image 4-2 is an example of the image taken and color palate used.

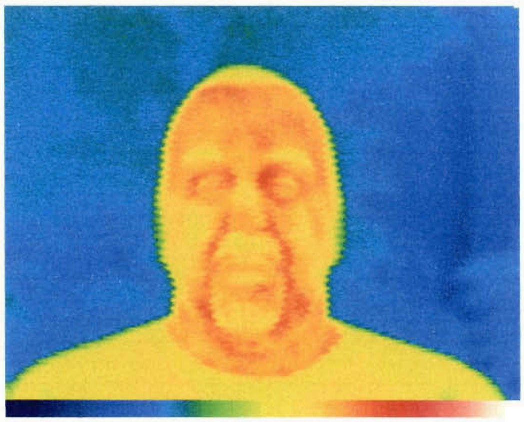

Image 4-2 Sample Thermograph Image

Although the facial temperature data is intended for a current database, there are many ways to also analyze the data. The average face temperature of all 40 subjects was found to be **89.45°**. Average male temperature and female temperature is represented in Figure 4-3.

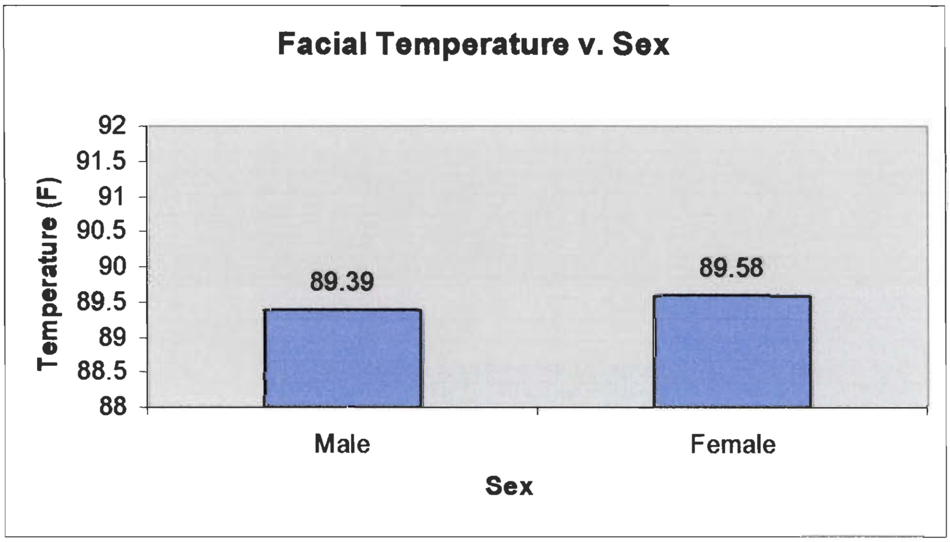

Figure 4-3 Facial Temperature v. Sex

Although the **.19** temperature difference in sex is very small, this does comply with past research into the subject. Facial temperature and age is also very interesting. As stated in Section 2.4.1, temperature decreases as age increases. Figure 4-4 adheres to this principal.

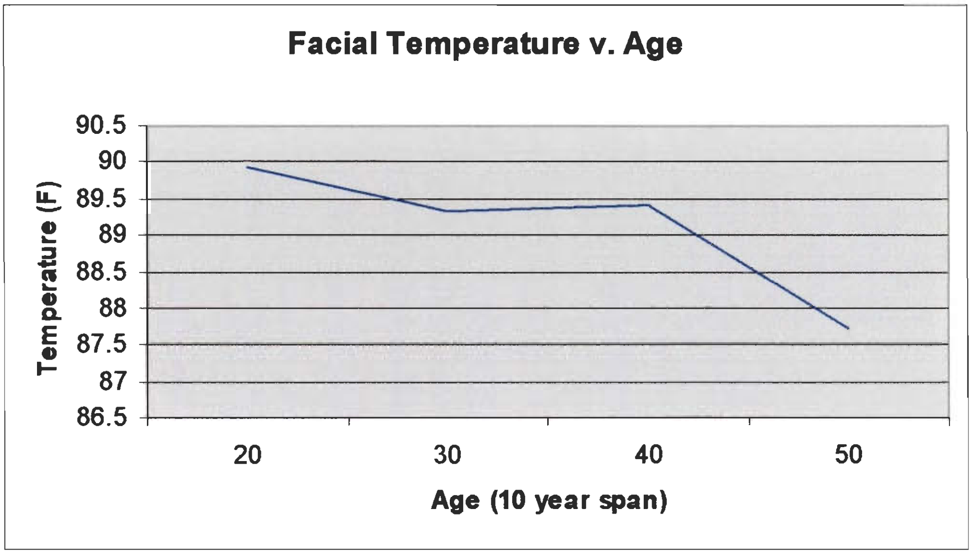

Figure 4-4 Facial Temperature v. Age

4.2 Core Body Temperature

Among the 40 subjects, 20 had there core body temperatures taken. This data is represented in Table 4-5. Figure 4-6 indicates there was no correlation between skin temperature of the face, and body temperature. Future research should be done to fully understand the relationship of skin and core body temperature.

Subject	Facial Temperature (F)	Core Body Temperature (F)
1	91.2	97.7
2	89.7	97.0
3	92.0	97.0
4	89.8	97.6
5	87.8	96.9
6	88.0	96.8
7	88.8	96.4
8	87.0	95.6
9	86.2	95.1
10	89.5	96.6
11	88.9	96.6
12	88.9	96.8
13	90.0	96.5
14	88.9	97.0
15	90.0	96.7
16	88.6	96.5
17	88.8	97.0
18	88.0	96.9
19	91.0	97.0
20	90.3	98.0

Table 4-5 Facial Skin Temperature and Core Body Temperature

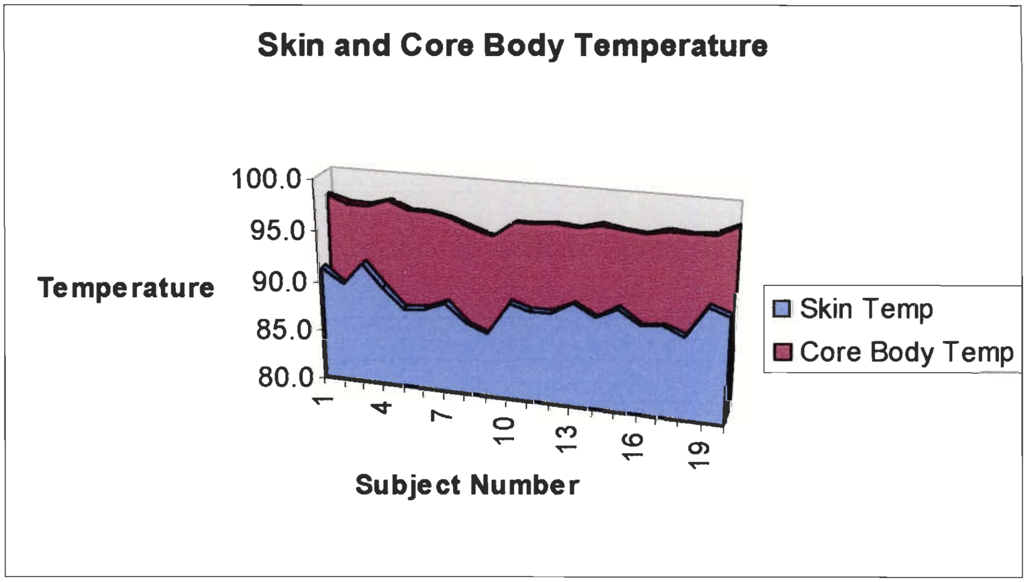

Figure 4-6 Skin and Core Body Temperature

4.3 Skin Acclimation to the Cold

Human skin has many dynamic properties, one of the most crucial to maintaining normal body temperature being the skin's ability to breath and acclimate itself sufficiently to the surroundings. In this experiment, temperature readings and images of a subject were taken in a controlled environment, indoors at 77° F. The subject was immediately put outside, where the air temperature was 32° F. There was a 5mph wind with 100% clear sky. After 10 minutes, the subject was immediately brought back inside, and images were taken every minute until the skin was acclimated and reached the same temperature as before.

The average skin temperature of the face before being subjected to the cold environment was 88.4° F. After the 10 minute period, the average temperature was 75.4° F. Image 4-7 and 4-8 show the thermal imager's dramatic depiction of this temperature change.

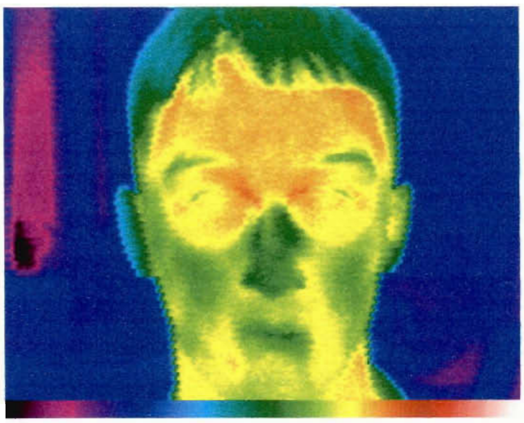

Image 4-7 Before

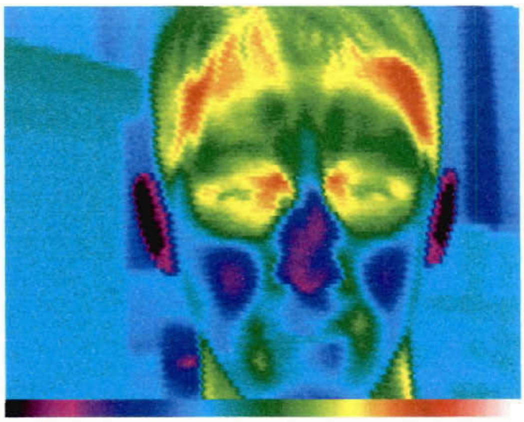

Image 4-8 After

After 13 minutes, the skin temperature rose to 89.1° F, warmer then the original temperature. Table 4-9 represents the time and their respective temperatures. Figure 4-10 is a graph of this data.

Time (min)	Skin Temperature
0	78.4
1	81.0
2	81.8
3	82.3
4	83.3
5	84.4
6	85.2
7	85.6
8	85.9
9	86.1
10	86.7
11	87.2
12	87.5
13	88.0
14	88.3
15	88.6
16	88.7
17	88.9

Table 4-9 Skin Temperature Acclimation

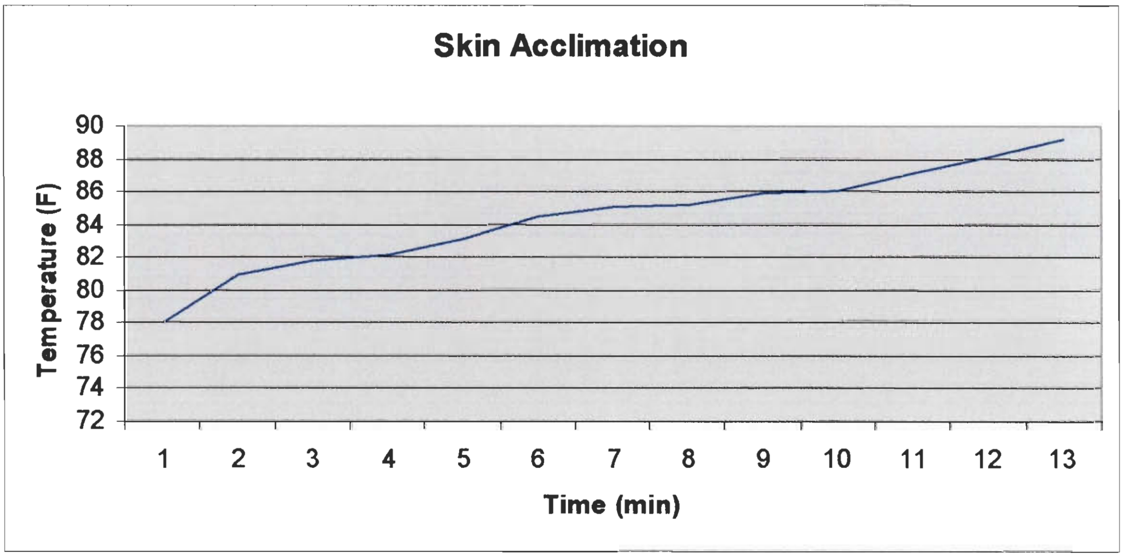

Figure 4-10 Skin Acclimations from Cold

From Figure 4-10, we can conclude that skin on the face will generally acclimate at a constant rate, although the most dramatic increase in temperature from the cold will occur within the first two minutes.

4.4 Skin Acclimation and Face Paint

A question to pose is whether face paint has any effect on the temperature or acclimation rate of skin on the face. Images 4-11 and 4-12 are of a subject before and after the application of camouflage face paint.

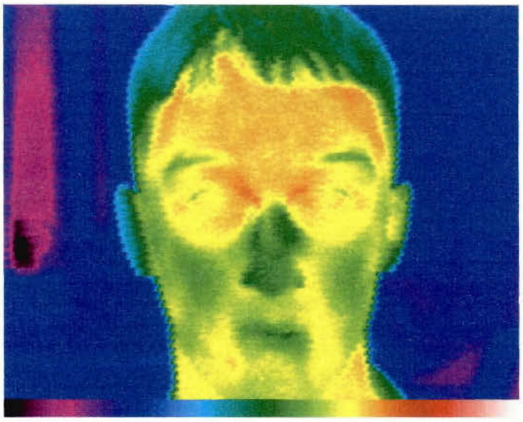

Image 4-11 without Face Paint

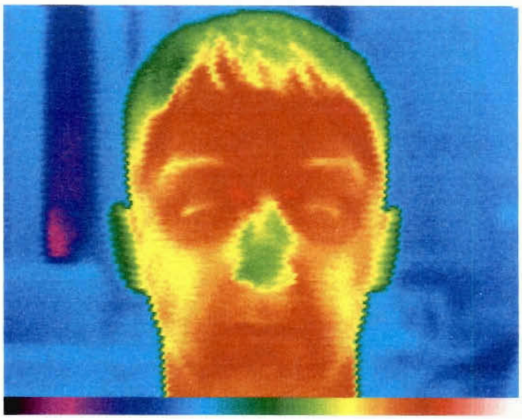

Image 4-12 with Face Paint

The thermal imager shows us a 3° rise in temperature with the addition of camouflage to the face. Although face paint does not seriously heat the skin, it is clear camouflage clogs skin pores and inhibits the skin's ability to breathe.

The previous experiment involving acclimation from cold temperatures was conducted, with the addition of face paint. Indoors, the average skin temperature with face paint was 90.5° F. Table 4-13 lists the temperature values after acclimation to 32° temperatures. Figure 4-14 graphs this data.

Time (min)	Skin Temperature (F)
1	78.4
2	81
3	81.8
4	82.3
5	83.3
6	84.4
7	85.2
8	85.6
9	85.9
10	86.1
11	86.7
12	87.2
13	87.5
14	88
15	88.3
16	88.6
17	88.7
18	88.9
19	88.9
20	90.1
21	90.3

Table 4-13 Skin Temperature Acclimations with Face Paint

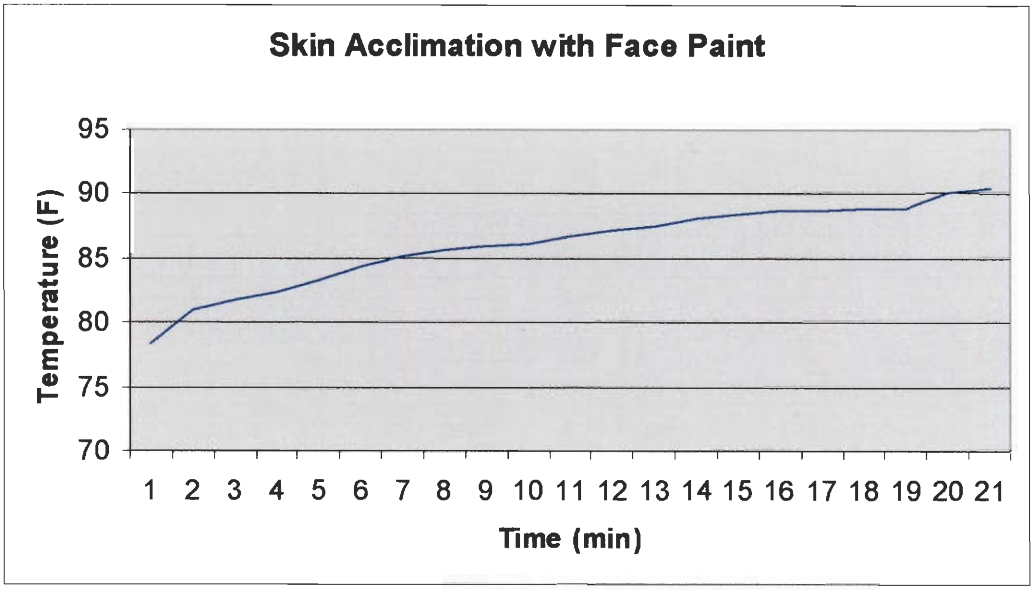

Figure 4-14 Skin Acclimations: Face Paint v. Time

With face paint on, the acclimation curve is much smoother. This is due to the fact the whole face has the same outer layer throughout; this is to say there is not as much deviation in the cheek to forehead temperature with face paint on as there is without it. The face paint acts as a mask, which to a certain extent distributes heat and cold throughout the face evenly. This feature, no matter how small it is, more then makes up for blocked pores as discussed earlier. It did however take approximately 9 minutes longer for the face to get back to its original temperature. Figure 4-15 shows us both acclimation graphs next to one another.

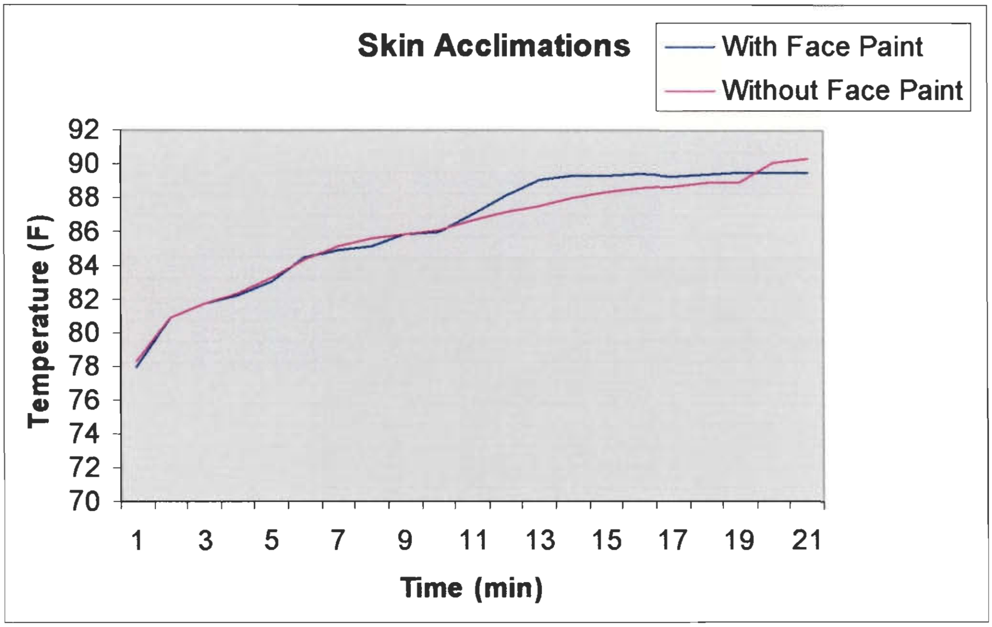

Figure 4-15 Skin Acclimations with and without Face Paint

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APPENDIX A

The U.S. Army Soldier Systems Center, Natick, MA

The U.S. Army Soldier Systems Center in Natick, Massachusetts is the Army's premier soldier-support organization. Natick Labs is responsible for the "science behind the soldier" including:

- Food, Clothing, Protective Equipment, Parachutes, Shelters, and Medical supplies
- Everything the soldier wears, carries, and consumes
- Focus is on supporting the soldier.

The goal of Natick Labs is simple: Provide America's soldiers with the best equipment in the world. Natick has consolidated full life-cycle management of soldier items into a one-stop, soldier support organization.

Although Natick Labs is responsible for many things, they work together with numerous organizations to research and develop the best products possible. Partners include:

- Deputy Commanding General for Homeland Operations
- Army Research Institute for Environmental medicine
- Navy Clothing and Textile Research Facility
- Integrated Material Management Center
- PEO Soldier, PEO Combat Support/Combat Service Support and PEO Chem/Bio Defense Teams
- Coast Guard Clothing Design and Technical Office

Engineers and researchers at Natick Labs play a crucial role in today's war on terrorism and in homeland defense. Products and people are sent all over the world to support military operations, and technical advice to support civil servants (firefighters, EMTs, law enforcement) is provided to protect communities.

Natick Labs currently employs 2,000 civilians, military personnel, and contractors. The combined annual budget is over $800 million.

APPENDIX B

FLIR Systems, INC

FLIR Systems, Inc, is a world leader in the design, manufacturing, and marketing of thermal imaging and broadcast camera systems for a wide variety of commercial and government applications. FLIR systems now own all products under the name Inframeteics. The Infraetrics Model 760 IR Imaging Radiometer was the machine used in this project. FLIR Systems also specializes in many areas, including:

- Condition monitoring
- Research and development
- Manufacturing process control
- Airborne observation and broadcast
- Search and rescue
- Deferral drug interdiction
- Surveillance and reconnaissance
- Navigation safety
- Border and maritime patrol
- Environmental monitoring
- Ground based security

FLIR Systems was founded in 1978, and has offices in Portland, Oregon, Boston, and Stockholm, Sweden.

APPENDIX C

Camouflage Face Paints

Current fielded camouflage face paint is designed to provide protection visibly, and to meet soldier acceptability and safety. Camouflage face paint is nearly odorless, and will not reduce the natural sensing capabilities of the soldier. More importantly, the use of face paint will not cause any health hazards, and will not induce toxicity if ingested.

The design criteria for camouflage face paint includes comfort in application and wearing, durability over time, appearance, resistance to perspiration, ease of application and removal, and compatibility to clothing and other equipment.

Face paints in the compact form provide passive camouflage protection in the visible and near infrared regions of the spectrum. The face paint is to be used on all exposed skin to provide a non-glossy color to the face and tone down highlights of the skin. The current Army issue compact is suitable for all climatic categories from the Arctic to the Desert.

The compact itself is an olive green cosmetic like container with a mirror to help in the self application process. The four compartments of the compact contain a different color of pigmented formulations. These include green, loam, sand and white.

The other form of camouflage, found in a stick, only provides protection in the visible region of the spectrum. The camouflage sticks consist of two cylinders, dispensers of grease paint material, each of different colors, joined end to end forming one stick. The colors include green and loam, green and sand, and white and loam. The application process involves pushing the sick through the dispenser from the opposite end.

APPENDIX D

Common Emissivity Values

Understanding Emissivity is an important part of thermal imagers and their applications. Emissivity is defined as the ratio of radiation emitted by a surface to that emitted by a black body at the same temperature.

The emissivity value of human skin is on average 1.0. Included is a list of common emissivity values.

Material	Emissivity
metals	
Aluminum: polished anodized	0.05 0.55
Brass: rubbed with 80-grit emery heavily oxidized	0.03 0.61
Copper: polished heavily oxidized	0.05 0 0.78
Gold: polished	0.02
Iron: cast, polished cast, oxidized sheet, rusted	0.21 0.64 0.69
Magnesium: polished	0.07
Nickel: electoplate, polished oxidized	0.05 0.37
Silver: polished	0.03
Stainless steel (18-8)	0.16

buffed oxidized	0.85
Steel: polished oxidized	0.07 0.79
Tin: plated sheet ***others***	0.07
Brick	0.93
Carbon: candle soot graphite	0.95 0.98
Concrete	0.92
Glass: polished plate Lacquer: white matte black	0.94 0.92 0.97
Oil: thick coating	0.82
Paint: oil-based	0.94
Paper	0.93
Plaster	0.91
Sand	0.9
Skin, human	0.98
Water: distilled ice snow	0.95 0.96 0.98
Wood: planed oak	0.9

Table D: Common Emissivity Values

APPENDIX E

Body Temperature Regulation

All Human life is only compatible with a narrow range of temperatures:

Temperature (C)	Symptoms
28	muscle failure
30	loss of body temp. control
33	loss of consciousness
37	normal
42	central nervous system breakdown
44	death

The power cost of various common activities is listed below.

Activity	Energy Cost (Cal/m^2 hr)
sleeping	35
sitting	50
working at a desk	60
standing	85
washing & dressing	100
walking (3 mph)	140
bicycling	250
swimming	350
unning	600

Approximately 80% of these costs are waste heat. The other extreme is cold weather; due to the fact your body must work to stay warm. The mechanisms which either are used by your body or affect its function are conduction, convection, radiation and evaporation.