The Harvard Fatigue Laboratory: contributions to World War II

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Submitted 23 April 2010; accepted in final form 9 June 2010

Folk GE (With the Editorial Assistance of Thrift DL). The Harvard Fatigue Laboratory: contributions to World War II. Adv Physiol Educ 34: 119–127, 2010; doi:10.1152/advan.00041.2010.— The war contributions of the Harvard Fatigue Laboratory in Cambridge, MA, were recorded in 169 Technical Reports, most of which were sent to the Office of the Quartermaster General. Earlier reports were sent to the National Research Council and the Office of Scientific Research and Development. Many of the reports from 1941 and later dealt with either physical fitness of soldiers or the energetic cost of military tasks in extreme heat and cold. New military emergency rations to be manufactured in large quantities were analyzed in the Fatigue Laboratory and then tested in the field. Newly designed cold weather clothing was tested in the cold chamber at −40°F, and desired improvements were made and tested in the field by staff and soldiers in tents and sleeping bags. Electrically heated clothing was designed for high-altitude flight crews and tested both in laboratory chambers and field tests before being issued. This eye witness account of the Harvard Fatigue Laboratory during World War II was recorded by Dr. G. Edgar Folk, who is likely the sole surviving member of that famous laboratory.

I spent the years of 1943–1947 on the staff of the Harvard Fatigue Laboratory. As I am likely the sole surviving member of that famous and unique laboratory, I feel it is important to record the exciting story of the laboratory’s contributions to World War II as well as to describe some of the notable scientists who made these contributions. The early years of the Fatigue Laboratory have been documented in at least one book (13) and several articles (4, 6, 16). The present article differs, however, in that our focus is on the Fatigue Laboratory’s war years and the period just afterward.

The laboratory had been created by the great biochemist Lawrence J. Henderson along with David Bruce Dill in 1927. It was given the name “Fatigue Laboratory” because one of its missions was to work with industry to explain the physiology of fatigue. Many of its large-scale projects consisted of studying the effects of heat and cold on individuals and attempting to make them more comfortable during work or exercise in extreme environments. A good example of this, from a few years earlier in the laboratory’s history, was the building of the Hoover Dam; workers in the extreme desert heat were succumbing to heat exhaustion and heatstroke, and there had been 13 deaths. Bruce Dill and John Talbott went to Nevada and ran physiological and biochemical studies on themselves and healthy work crew volunteers in the heat. They recommended ensuring that the men had cooler conditions in which to sleep and recuperate after working all day in the heat and also to add copious amounts of salt to the men’s food (7).

The Fatigue Laboratory was one of the first exercise laboratories in the United States (U.S.) and became the leading center in the U.S. devoted to research on exercise physiology. There was a hot room that served as an “artificial desert” that could be operated at temperatures up to 115°F and a cold chamber that could be run at temperatures from 40°F down to −40°F. Both were equipped with treadmills and equipment to measure subjects’ physiological responses, including metabolic rates at rest and during exercise.

At the time I joined, this laboratory had the only experimental high-altitude chamber in the U.S. It was installed in the cold room, and experiments were done on oxygen masks, the bends, electrically heated garments, and the physiological effects of suddenly breathing air containing low levels of oxygen. Our altitude chamber was a model instrument, but it was scarcely used while I was at the Fatigue Laboratory; there is one early technical report on its use in 1942. Very quickly during the war, new altitude chambers were constructed at various places throughout the U.S., most sponsored, of course, by the Air Force.

During the war, the day-to-day director of the laboratory was William H. Forbes, but the person who had developed the interest in extreme environments and acted as director after L. J. Henderson had retired was David Bruce Dill. Dill, however, had been commissioned in 1941 and left on temporary assignment to the Aeromedical Laboratory at Wright Field in Dayton, OH. After 2 yr, he was transferred to the Army Quartermaster Corps in Washington, DC, where he attained the rank of Colonel. Although at a distance during most of the war, Dill was able to stay involved and “help direct the program of the laboratory toward the solution of pressing military problems” (6).

The expert on cold was Harwood Belding, and the expert on heat was Robert E. Johnson. Working with Belding, I was to take charge of the cold chamber and, using between four and eight soldiers as well as myself as subjects, develop improved cold weather clothing and equipment. At the Fatigue Laboratory, we were all subjects in any experiments that we asked the soldiers to endure.

Three especially effective researchers, who became my lifelong friends, were Robert Darling, Fred Sargent, and Robert Kark, all of whom had been at the Fatigue Laboratory since before the war. All three worked throughout the Fatigue Laboratory, although Bob Darling restricted his activities to the cold room at about the time I arrived. Sargent, an expert on the physiology of aging, ran his own program, which also operated across all research areas. Figures 1 and 2 show photographs of some of the Fatigue Laboratory’s war-time staff.

Typical Cold Room Experiments

The Fatigue Laboratory’s program to test clothing and equipment for use in cold climates was coordinated with a
similar program at the Climatic Research Laboratory in Lawrence, MA (later moved to Natick, MA). This facility was developed during the war and had been patterned on the Fatigue Laboratory; John Talbott became its head. The two laboratories shared a company of soldiers who had volunteered as subjects.

The usual assignment from the Quartermaster Corps of the Army, the Air Force, or the Navy was to describe the insulation value of various garments both when dry and when wet. The insulation might be wet because of immersion in freshwater or saltwater, from rain, or from perspiration soaking the insulation. The Fatigue Laboratory had developed a variety of techniques and calculations to answer these questions. The answer for each garment or group of clothing was usually expressed in terms of the Clo value.

One Clo is about the insulation of a business suit for a person sitting in an environment of 70°F. A soldier remaining inactive at −40°F would require an insulation of ~6 Clo. Of course for various garments, hand gear, and especially foot gear, the Clo value would have to be measured individually. These units could also be used to measure the insulation values of fur on various animals as well as human clothing.

This system and the formula for measuring the Clo value of various outdoor outfits were developed a few years earlier by Alan Burton and colleagues Gagge and Bazett (10). Alan Burton was the great cold weather physiologist who worked in England and Canada during World War II. He organized and led a cold weather school in Toronto, which Bob Darling, Robert Kark, and I attended in preparation for camping in the cold. Later, in 1956, Alan Burton was President of the American Physiological Society.

There were other ways of measuring insulation: copper models of a typical human body and models of the hand and the foot (Fig. 3) were used to measure heat flow from the interior source of the models when they were dressed in different garments. These results could be checked against actual heat flow from human subjects in the cold room at various temperatures.

There were three techniques used for measurement during the recording of insulation of various garments. The first, and major, measurement was recording the skin temperature of 10 parts of the body; these locations have been standardized in the literature. Because the source of heat was more important in some parts of the body than in others, these measurements were weighted as far as the surface area for that particular region was concerned. The second measurement was energy metabolism during the wearing of garments while either completely stationary or walking on the treadmill in the cold room. The third measurement was made with a radiometer to record radiation from the surface of the garments.

When doing experiments on human subjects, we used a questionnaire to find out their health on that particular day. We then taped thermocouples on the skin to measure skin temperature at the 10 standardized body points. We had the subject(s) dress in the experimental uniform being studied. Next, we would take them into the cold room, seat them as comfortably as possible considering the unpleasant environment, and give them a mouthpiece and a clip on the nose. The mouthpiece was used for ventilation so that we could measure the metabolic rate.

Fig. 1. Lunch break at the Harvard Fatigue Laboratory. Back row (from left to right): S. M. Horvath and G. E. Folk. Front row (from left to right): Ruth Cherry, W. H. Forbes, Sally Smith, and H. D. Russell. Photograph circa 1944. From the personal collection of G. E. Folk, photographer unknown.

Fig. 2. Cold chamber staff. From left to right: H. D. Russell, H. S. Belding, and G. E. Folk. The building in the background is the Harvard Business School; the Fatigue Laboratory was in the basement. Photograph circa 1944. From the personal collection of G. E. Folk, photographer unknown.
One day, Donald Griffin decided he needed to do an extended experiment on metabolism in the cold. Metabolism was measured by breathing oxygen out of a tank, which recorded (on paper with a pen) the oxygen used by each breath. When exhaling, the air from the lungs passes over the CO2 absorber. Donald Griffin asked me to dress appropriately for −40°F and to breathe out using this metabolic equipment in the cold room, which had been lowered to this temperature, from 8:00 AM until 8:00 PM. If the experiment with me succeeded, then he would carry it out on one of the soldiers assigned to the laboratory. By the seventh and eighth hour of breathing oxygen at −40°F, I began to wonder what dire effects might occur. There were none, however.

We had read articles about military barracks in the cold regions that had caught fire while the occupants were sleeping. I was given the assignment of determining what clothing should be worn when escaping a fire at an air temperature of −40°F and to determine how fast to run to maintain body temperature when inadequately clothed in such an extreme environment. Two soldiers joined me after I first tried this test. After several changes of clothing, we finally decided that the long woolen underwear issued to the troops in the cold regions would be typical of how soldiers would be clothed when they ran out of a burning barracks. I did wear gloves and tennis shoes and had a scarf around my face. We began at a moderate speed, and the balance between heat loss and heat gain proved adequate. We kept increasing the speed, and I found that I was perfectly comfortable to run at 7 miles/h in just woolen underwear at −40°F for at least 30 min. Afterward, the two soldiers repeated the process so we could write a report to the Army Quartermaster General and the Air Force as to what was reasonable emergency garb to wear when escaping from a fire in extreme cold.

I recall an interesting experiment done with the soldier subjects concerned with the encumbrance that is found when heavy garments are worn in the deep snow and the severe cold. Of course our Arctic uniforms, good for −40°F, were quite heavy. I wondered how much extra energy it took to wear these uniforms and believed that I could fractionate this amount of extra energy due to the weight of the clothing and its encumbering effect. I named the possible contribution of the encumbering clothing “The Hobbling Effect” (1, 2).

Another intriguing problem assigned to me was the movement of air within Arctic clothing. The Inuit had solved the problem of trapped moisture several thousand years ago. We had studied their clothing and diagrammed it for the purposes of developing clothing for the Army. Therefore, we could focus on the effect of trapped air within not only Arctic clothing but also even within the fur of a sled dog. How much does insulation change when a person is resting in an Arctic uniform and when there is action because the person is walking, perhaps in deep snow? Much to my delight, I was asked to invent an instrument to measure the insulation when the uniform covering an arm was ventilated and moved or when it was quiescent. In the laboratory’s machine shop, I worked with a machinist to design and make a copper artificial arm that could be moved and pumped and studied with different kinds of insulation. I was also able to put the hide and fur of a sled dog on the artificial arm to determine the insulation of a sled dog while at rest and again while running: the insulation decreases when it is moving.

Although World War II aircraft were not pressurized or heated, some flew at heights of 25,000–30,000 ft, as high as Mt Everest. Harwood Belding was supervising the work of developing electrically heated suits for the crews of the B-17 Flying Fortresses, the high-flying heavy bombers that were sent out on missions over Berlin. This gave us a lot of testing to do on ourselves to figure out the optimum way to distribute and calibrate the electrical heat over hands, arms, legs, and the torso at −40°F, the environment experienced by our aviators on those flights. Thus, we did many tests with experimentally heated suits on how to best provide heat and what was the optimum amount of heat needed by the various parts of the body at that temperature. An example, from a test on electrically heated gloves, is shown in Fig. 4.

One of the tests was designed by Donald Griffin, and I was the subject. I dressed in the experimental electrically heated suit and entered the cold room, which had been lowered to −40°F. Don then ran electric wires from the different points in the suit to a row of rheostats. His job was to raise or lower the heat in the various parts of the suit, and my job was to tell him if I was too cold or too hot in that area. When we started out, I confirmed that I was cold all over. Soon I was telling him “My arm is too cold... my foot is too warm... my backside is too cold... my elbow is now too warm...” and Don would record figures and adjust the rheostats, and in this way we could ultimately determine the most comfortable temperatures for which parts of the body when at temperatures of −40°F. We felt inspired by the knowledge that our aviators would be wearing suits like these, heated to the temperatures determined by us, in their life-and-death missions in the war.
As always, after any experiment commissioned by the government, we wrote reports for Col. Bruce Dill, or other appropriate officials, in the Quartermaster’s Office. In this case, our findings were also sent to General Electric, where the suits were designed and produced using our figures.

Donald Griffin was probably the staff member who became most famous after the war. He was the most imaginative researcher at the Fatigue Laboratory and was later elected to the National Academy of Science as an outstanding Animal Behaviorist.

Cold Injuries and the Battle of the Bulge

Much of our effort was devoted to preventing cold injuries, especially of the feet, the hands, and the face. These injuries differed in respect to several factors: the conditions under which they occur, the rapidity of their development, the severity of the injury, and their characteristic features (11).

Our Armed Forces assigned to the Northern regions had injuries due to dry cold. They encountered two kinds of injuries: true frostbite, in which the tissues actually froze and formed ice, and milder injuries, in which the tissues were damaged but not actually frozen. Of course, frostbite can develop with remarkable rapidity, but in the Fatigue Laboratory we were more interested in those cases that developed gradually over a period of days. This type of frostbite is caused by direct contact between the exposed part and a cold object, such as delicate instruments in a cockpit when the air temperature is \(-40^\circ\text{F}\), as often the case during high-altitude flying.

In another group of injuries, wetness is as important as the temperature as low as \(-40^\circ\text{F}\), it was known that the standard leather military boot was inadequate for cold weather service. Such boots were not impermeable to moisture and did not permit extra pairs of socks to be worn. If soldiers were serving in trenches or foxholes under snow or wet conditions, they must be dressed with three pairs of wool socks on their feet. Therefore, the Fatigue Laboratory’s tests included a boot with a higher last, so that more socks could be worn by the soldier. After testing, the Fatigue Lab recommended the L.L.Bean shoepac, a sturdy boot with a rubber sole and sides, a leather upper that laced around the ankle, and room for three pairs of socks.

Harwood Belding dressed a mannequin in this uniform (which included footwear) and presented the design to Col. Georges Doriot, an officer in the Quartermaster Corps. Col. Doriot responded favorably to the advice and discussed with numerous generals the advisability of changing the cold weather foot gear of the infantry being sent to Europe. Unfortunately, some of the generals insisted “Our boys must march on leather!” To show his dismay and disagreement with the decision, Col. Doriot responded by installing the Belding mannequin, complete with shoepacs and three pairs of socks, in a glass case in the Quartermaster Corps’ office, adding a note stating that this uniform was recommended in early 1942–2 yr before the Battle of the Bulge.

It is well known that during the Battle of the Bulge in the winter of 1944–1945, our soldiers resisting the attacks of the Germans near the Dutch border were inadequately clothed. At times the air temperature was \(-30^\circ\text{F}\). They spent prolonged periods in trenches and foxholes, where their feet were exposed to cold and moisture; temperatures were often around freezing, and trenches were at times flooded. For a long part of the battle, their footgear consisted of the standard leather boots designed to hold one pair of wool socks. Later on during the battle, some old-fashioned buckle overshoes were issued, but you can imagine the problem of trying to get a wet army leather boot into a rubber overshoe. Additionally, the boots were difficult to rapidly remove to replace wet socks. Because of this inadequate insulation, coupled with cold, wet, cramped, and often immobile conditions, many soldiers ended up with trench foot, and this was a big factor in the Battle of the Bulge. During that winter, U.S. casualties admitted to hospitals because of cold injury (both trench foot and frostbite) numbered as many as 17,457 in 1 mo and for several weeks approached 50% of all battle casualties (14). There were complaints against Col. Doriot because of the Battle of the Bulge until he took the leading officers to his model soldier under glass and showed them what boots he had recommended very early in the war. Doriot continued to advocate for proper clothing and footwear for the soldiers and finally received support from Gen. George Marshall.

Contribution of the Fatigue Laboratory to the Battle of the Atlantic

Our sailors and flight crews were at high risk of cold injury from prolonged immersion in freshwater or saltwater. When troop ships were torpedoed, survivors might float in the water for quite a while before they were rescued. The crew in aircraft that were shot down were often left floating in the ocean for hours. They suffered from “immersion foot,” which was described above. The military supplied some ship and aircraft

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personnel with immersion suits, which were rubber garments to be pulled on over their clothes at times of emergency in the water.

In 1943, we were sent a few dozen of these immersion suits and asked to don them under various circumstances and to give suggestions for a redesign. The simulation studies were to be circumstances where a ship might be about to sink or an air crew had a forced landing in dangerous waters; such crews might pull on immersion suits over regular clothing. These suits could be closed tightly around the face and neck so that water would not penetrate and the person would float on the surface. Our testing had to involve not only cold weather exposure but also the buildup of moisture inside the exposure suits.

With a number of the soldiers and myself as subjects, I did the following experiments: we simulated men working on the deck on a mild day who must evacuate a ship in water at 60°F, then in water of 40°F, and then at various temperatures all the way down to −40°F. We followed the typical protocol of dressing in military uniforms, putting on the exposure suits, walking on a treadmill in our hot chambers, and then going and sitting in the cold room at various temperatures. Such experiments resulted in lengthy reports indicating how long these uncomfortable situations could be tolerated and how they might affect a soldier’s ability to fight against an enemy.

We measured the amount of moisture accumulated during the work and then what the insulation would be after it became saturated. Of course considerable moisture accumulated, even when the outside temperature was −40°F. That was exactly the type of information that the military wanted to know: specifically, how much was the loss of insulation and how fast would that occur after exercise, presumably on the deck of the ship?

We recorded the time it took us to get into the exposure suits and recorded what sizes were needed for a variety of types of individuals. The major problem of design we identified was that it was difficult to get into the suit with regular clothing, assuming the survivors would not have time to modify the garments they were wearing. We did get feedback later that implied that while many exposure suits were issued, it was only under very special circumstances that there was time to don them before evacuating into the water. We also received information that in some cases of using the suits in cold regions, the troops would not have survived had they not worn the exposure suits.

An essential theme in the study of the footgear and in major experiments like wearing an exposure suit in very cold conditions always involves the recording of vasomotor function. At times the blood vessels in the skin are vasoconstricted and at other times they are vasodilated. We expected to make measurements of the activity of the skin vessels in every experiment during exposure to the cold. One of the reasons was that the human body has an emergency mechanism to try to prevent the freezing we have been discussing in this article. This mechanism consists of episodes of warm blood surging into vessels that have been constricted due to cold. These episodes of vasoconstriction followed by temporary vasodilation are called Lewis waves (after the person who discovered them), or cold vasodilation. In many of our reports, we had much to say about this automatic protective mechanism of the body, which tries to prevent cold damage caused by decreasing blood flow to the skin.

Before and during the war, two important principles came out of the Fatigue Laboratory: namely, the acclimatization to heat and the acclimatization to cold. Although initial experiments on acclimatization were done in our cold chamber, the best experiments on cold acclimatization were done later at the Fort Knox Armored Medical Research Laboratory, whose more extensive facilities allowed for long-term cold acclimatization studies.

Field Studies

An important and unique feature of the Fatigue Laboratory was its custom of checking the artificial experiments done in environmental chambers against rigorous testing in the field. The rule had been to be prepared to, if necessary, pack instruments and take measurements in the field. There had been a long tradition of this, such as Bruce Dill’s successful high-altitude expedition in the Andes as well as heat studies in the Nevada desert. Robert Johnson developed field kits for doing blood analysis during field tests in the heat and also in the cold in Saskatchewan.

A leader in this tradition of making physiological measurements in the field was Per Scholander from Norway, a distinguished investigator who often worked at the Fatigue Laboratory during the war. He led various field excursions from there; for want of a better name, he called this area of work “Expeditionary Physiology.” Later, carrying out this inclination to fulfillment, Scholander established a physiological laboratory at Point Barrow, AK, with Lawrence Irving from Swarthmore College. Two of the many physiologists who would later venture to Point Barrow to work in this laboratory included Donald Griffin and myself.

One important field test I was involved in took place in Newfoundland, Canada, where I was put in a military uniform and sent to work with an international team on the equipment for soldiers to use while camped in deep snow without barracks. Made up of officers from Canada, America, and Britain, this was a very exciting group to be with. We lived in the countryside along with a Canadian infantry Colonel who had brought ~100 troops to be our subjects. We were to test appropriate new equipment and teach these soldiers how to live in deep snow, even on mountain tops.

Part of my assignment there was to accompany flight crews in the Canadian flying boats (Canso aircraft) as they patrolled for German submarines. I had to be in the uniform provided by the Quartermaster Corps in case our flying boat went down and we were captured by a German submarine. My function while making these flights was to record the meteorological environment within the cabin and to recommend improvements in the clothing of the flight crew.

A member of the team in Newfoundland was Henry C. Bazett. An Oxford scholar who had served as a British medical officer in World War I, he was also a professor at the University of Pennsylvania and one of the team who had earlier developed the system of Clo units to measure insulation. But above all, H.C. Bazett was a physiologist who liked to be in the outdoor environment. Later (in 1950), he went on to become President of the American Physiological Society.

A famous explorer, Paul Siple, was also assigned to our unit in Newfoundland to improve the equipment of soldiers in action. I soon found myself working with Paul who, as a boy...
The Fatigue Laboratory was selected to test the idea. This meant that the staff and soldiers were to have a distinct break from routine laboratory work to go into the field and live for 7 days on pemmican while blood samples were taken to study the effect of this extreme diet. Because of what you might call the distractions of civilization, the study was to be done on a remote island near Wood’s Hole, MA.

The first island in the chain that forms the area referred to as Wood’s Hole is Naushon and the second is Pasque Island. The two are separated by a strait known as Robinson’s Hole. This had been a favorite fishing spot of an elite club that met there to catch striped bass. Since that species of fish had disappeared from the area, the elaborate buildings of the club on Pasque Island were abandoned, and it was an ideal locale for several soldiers and staff members to do the pemmican experiment. We were transported by a lobsterman named Olsen, who lived on Pasque Island and was considered to be the lobsterman who was farthest away from the mainland. Furthermore, his house was considered the oldest house in New England.

The experiment began, but after the second day, all of the soldiers refused to eat the pemmican, saying they preferred to “go hungry rather than eat the stuff.” It made some of them nauseous and left a waxy layer on the roof of their mouths. The Fatigue Laboratory staff did manage to eat the pemmican for the entire study, although two of us, Erling Asmussen and I, had to quit the experiment early and leave the island because of crises within our respective families. In the study, all subjects developed severe ketosis from the high-fat diet or from not eating at all. Thus, it will come as no surprise that the resulting report did not recommend pemmican as a military ration (5), but we had paid homage to Stefansson.

Other Notable Workers

The team of workers in the laboratory was amplified continuously as the war progressed. Probably the most famous was F. J. W. (Jack) Roughton, FRS, who had been a Foreign Fellow in the Fatigue Laboratory before World War II and returned as an official consultant during the war. A decade earlier, with N. U. Meldrum, he had described how carbonic anhydrase plays a critical role in the transport of CO₂ from the tissues to the lungs. Roughton had come from England as a Visiting Research Fellow in War Science and Medicine at Harvard, and he used the Fatigue Laboratory’s elaborate facilities for the analysis of blood to work on military-related problems such as carbon monoxide poisoning and high-altitude physiology. My association with him was mostly to help him to pack each time he returned to England.

There were many interesting visitors to the laboratory. One, Sir Stanton Hicks, a Colonel in the Australian Imperial Force, was a scientist and medical doctor who had advocated using scientific principles to develop military rations that were based on nutritional—not monetary—value. He visited the Fatigue Laboratory to discuss and promote his findings.

Edward Adolph studied the effects of thirst, and he often came to the Fatigue laboratory to exchange ideas. He had spent several months at the laboratory a few years earlier and had modeled his own laboratory at the University of Rochester based on those experiences. He later became President of the American Physiological Society.
One day when I was alone in the laboratory (the rest of the staff were in the field), a distinguished-looking man with a Van Dyke beard walked in and said he would like to look around. This was Sir Hubert Wilkins, the famous Australian-born war photographer and polar explorer; he had been knighted for making the first trans-Arctic flight from Point Barrow, AK, to Spitsbergen, Norway. Wilkins had also commanded the first submarine to pass underneath the Arctic pack ice and navigated the first airplane flight over the Antarctic continent (which served as a mapping and photography mission). Much later, in 1970, I visited the Antarctic island where his plane had taken off; the volcanic lava was still marked with the lines of white lime that delineated the outline of the runway. At any rate, I showed Sir Hubert through the laboratory, and he witnessed some of our soldiers testing the insulation in a new type of winter uniform. I later learned that he had been hired as a consultant to the Army Quartermaster Corps on hot and cold weather clothing and survival techniques and advised the military on aviation and submersible craft research (14a).

This exchange of talent worked both ways, as it was also the policy of the laboratory to loan its staff to the military. Harwood Belding, who had built the first thermal mannequin for the U.S. military, was given the rank of Major and sent to England in an advisory capacity. He was in London during the Battle of Britain and described his response upon hearing the V-1 “buzz bombs” overhead. These small, unmanned, airplane-like bombs (early cruise missiles) were programmed by the enemy to target specific locations in London; they made a putting or buzzing sound until they neared the target, at which point they became silent as they homed in on the target. Alerted by the sudden silence, Harwood’s procedure was to scramble under a bed, knowing that a bomb would soon explode nearby. But the V-1 buzz bombs were soon followed by the V-2 rockets. These were more sinister because they were silent and exploded without warning, almost causing London’s morale to fail. These ballistic missiles almost won the war for Germany; the British had tolerated the buzz bombs and bombs dropped from planes, but they could not tolerate these silent killers—the war ended just in time.

Nonhuman Subjects

Although humans were the subjects of most Fatigue Laboratory studies while I was there, I found when I looked at the past publications from the Fatigue Laboratory that there were reprints concerned with comparative physiology. The system seemed to work this way: although the goal was always to obtain knowledge on human physiology, the techniques were also used on some convenient vertebrate to record their physiology. For example, someone had brought two crocodiles into the laboratory, and their blood was analyzed with the same techniques as ordinarily applied to human subjects. So several bits of comparative physiology came into our work at the Fatigue Laboratory. It was also no surprise that animals in the free environment were sometimes studied because in Bruce Dill’s classic volume, *Life, Heat, and Altitude*, he not only described human physiology but also included information on domestic animals at high altitude garnered from his expedition to the Andes. He even included a section about the different rates at which ants at sea level walked at various temperatures.

During one of Dill’s visits from Bethesda, MD, during the war, I was sitting making measurements on soldier subjects exposed to −40°F. Bruce burst in and asked, “Do skunks hibernate?” I happened to have looked through literature to find that, and I replied, “It is not known.” Bruce looked at me firmly and said, “Well, get going then!” I must say that after 3 yr of working with human subjects, but with a prior interest in comparative physiology, this gave me the confidence to plan a career in which one could do experiments on “mice or men.” Later I did do the experiment on both skunks and raccoons and found that while both remain quiet and resting in their burrows in midwinter, neither animal hibernates.

During the second year of my war work there, Donald Griffin left the Fatigue Laboratory because he had been appointed a Harvard Junior Fellow. He continued his research at the Biological Laboratories. One evening during the war, he asked me for some assistance because four hands were needed. He had received a military contract because of a rather bizarre suggestion someone had sent to military headquarters. The person knew that many people in Japan were living in straw-roofed houses. The theory was to have airplanes fly over these towns and cities and release bats carrying an incendiary object. The bats would then return to their usual habitat and crawl into the straw of the houses, and the small incendiary device would set the house on fire. The simple question asked of Griffin was “How much weight could the common bat, *Myotis*, carry as it floated downward from the airplane?” Although Griffin did determine how much weight this small bat could carry, the incendiary plan was never put into effect, although it was tried out in a model Japanese village in a military camp near Washington, DC. Years later, I was giving a lecture at a medical school and mentioned the bat story to the students. A member of the audience said that while in uniform, he had helped to build the model village for the test.

Another extensive piece of comparative physiology we did resulted from an elusive pigeon. While Bruce Dill was still in Bethesda, MD, he asked us to determine what laboratory animals would be useful in extremely cold weather for testing dangerous chemicals. Because the tolerance of ordinary laboratory animals could not be found in any literature, we took the core temperatures of a series of animals exposed to extreme cold and removed them from the cold when their body temperature started to drop. One of the pigeons we were studying escaped in our cold room while it was running at −40°F. At first, we could not find the bird in the many pieces of equipment in the cold room; 3 days later we found it, and kept it a cage, and studied it for several more days. The pigeon appeared totally healthy in all respects, and there were no signs of frostbite anywhere on its body from its exposure to −40°F. We compiled these results with those from other laboratory animals and published the study in the journal *Science* (12).

Continuing Studies

The war finally ended in 1945, and people went back to their own lives. I was told that I could continue on the staff of the Fatigue Laboratory and could work toward a PhD.
degree. I would be put on a half-time basis. There was already a precedent for this: both Sid Robinson and Steve Horvath had received their PhDs while on the staff of the Fatigue Laboratory. Both later became Heads of Departments: Robinson at the University of Indiana and Horvath at the University of California-Santa Barbara.

But being accepted into Harvard’s PhD program wouldn’t be easy; there was a constant stream of people from the military trying to get into graduate school. And because many were interested in future careers at research laboratories, there was a growing shortage of teachers. Naturally, the universities did not want to train PhDs who would leave academia for higher-paying jobs. Fortunately, my earlier years of teaching bright students of ages of 16–18 yr had convinced me that I would enjoy teaching 50% of my time and putting the other 50% into research. To my delight, I was admitted into the graduate program. Later, my sponsor, John H. Welsh, told me that had I not stated my intention to teach half the time, I would not have been admitted. My thesis topic was biological clocks.

Meanwhile, many physiological experiments continued to be supported by military contracts and later a new research organization called the National Science Foundation (NSF). One interesting experiment we did with NSF support while I was working on my PhD thesis was to develop a lifeboat ration. The Fatigue Laboratory had done numerous studies on nutrition over the years; finally, we were asked to select and test a ration to be put in the lifeboats of ships. It was a hot summer, and seven of us immediately went on the prescribed diet, which included only a very small supply of drinking water.

Two of the subjects were large, athletic medical doctors, one of whom was Bob Darling. Although body size varied among the subjects, we did not assign the rations on a per weight basis but apportioned them equally. I was very interested in any changes in attitude and outlook as the 7 days went on, particularly since we had so little water. I would say there was a graded response, with the smaller subjects affected the least and the larger individuals suffering the most. That in itself was not surprising, as they had consumed less water per pound of body weight. As one of the shorter individuals, I did not feel particularly bad, but I was shocked to watch Darling, one of our most brilliant scientists, lapse into slurred speech and a very unsteady walk. Although no overt mental decline was obvious, I would expect critical tasks such as decision making would also be impaired.

During this time, I had several opportunities to work with Bruce Dill, who was back from Washington. Bruce started a vigorous experimental program; his subjects included me and about eight paid subjects who were students Bruce had recruited. We were to walk fast in the hot summer sun for an hour or longer, after which Bruce would take a blood sample. As the only staff member, I led the subjects at the rate requested and came in at the head of the column—some students weren’t used to such exercise in the heat. Then, we all lined up to have what I think was an arterial blood sample extracted.

During the next few weeks, Bob Kark and I were the only staff members available, and we served as Bruce’s subjects on the Fatigue Laboratory’s treadmill testing boots. This was the same treadmill upon which studies were done on the ability of a famous marathoner, Clarence DeMar. He had won the Boston Marathon seven times, still a record in Boston, and the Fatigue Laboratory analyzed his heart rate, stroke volume, and sweat rate at various running speeds. Our boot-testing runs were much more humble.

In both his professional and personal life, Bruce Dill could be a hard driver—but he also had a softer side. I remember one weekend at the Dill’s old farmhouse in New Hampshire, where Bruce and his wife, Cloris, enjoyed having staff and students visit. Bruce had invited my family, including 3-yr-old Victoria, to spend a weekend. Bruce never seemed to relax, so he and I spent the waking hours chopping brush in the woods behind the farmhouse. Then, during rest stops, Bruce took every opportunity to scoop Victoria up and bounce the delighted child on his knee. It’s no wonder that many who knew Dill felt affection and loyalty for the man, along with respect and admiration for his accomplishments.

Another experiment that was running while I was writing my thesis was designed by Bob Kark. It was an exercise experiment to be run on the treadmill; Bob wanted a detail of a chemical change during running that required changes in blood glucose. The technique had been developed so that a drop of blood could be measured for the glucose. Because any staff member could be asked to be a subject, I soon found myself on the treadmill day after day for the experiment. The drop of blood was taken by lancing the end of the finger, and, as I walked fast or ran on the treadmill, finger after finger was lanced for the valuable drop of blood. Of course it was necessary to go on to the other hand. The next day, Bob started back on my first hand and went all the way through my 10 fingers again. The same occurred on the third day. This was rather routine behavior for our laboratory, and staff often dryly commented that it was difficult to walk across the laboratory without someone asking you to sit down so they could make an arterial puncture for a sample of blood. The experiment with Kark was satisfactory except for one thing: each evening I was typing my PhD thesis. By the time each finger had been lanced three times, it became more difficult for my fingers to press the typewriter keys.

An Ending and a Beginning

At this time, the days of the Fatigue Laboratory were nearing their end. L. J. Henderson had died in 1942, other major supporters in the upper echelons of Harvard had retired, and University President Conant had never been one of the laboratory’s backers. Although government support was available, university policy prohibited such funding after the war. The staff was disappearing to accept positions at other universities. W. H. Forbes went to Harvard’s School of Public Health, and R. E. Johnson left to continue his nutritional research at the Army Medical Nutrition Laboratory. Fred Sargent left to work with Johnson. (Sargent later founded the International Biometeorological Society, an interdisciplinary group that flourishes today.) Harwood Belding became Scientific Director at the Climatic Research Laboratory’s new facility in Natick, MA. Bob Darling joined the College of Physicians and Surgeons at Columbia University.
Bruce Dill formally left in late 1946 to become Scientific Director at the Medical Laboratory of the Army Chemical Corps. However, he continued teaching at Harvard for many years as a visiting lecturer in physiology in the School of Public Health. Bruce also served as President of the American Physiological Society in 1950.

As Dill walked out of the Fatigue Laboratory for the last time, he turned to me and said, “Ed, you’re in charge!” So, from then until I left several months later, I was an unofficial acting director, signing the Fatigue Laboratory payroll, doing research, and performing various other tasks.

In June of 1947, I received a PhD from Harvard University at a very unusual commencement. Our speaker was Gen. George C. Marshall, who was to receive an honorary degree that day. During the war, Marshall had been Army Chief of Staff under President Roosevelt and had been recently appointed Secretary of State by President Truman. During his speech, he declared, “I propose that this nation assist the recovery of the two countries with whom we were at war, Germany and Japan.” And he recommended specific sums of money that he felt should be sent to assist in the recovery. This European Recovery Plan soon became known as the “Marshall Plan,” and, in 1954, Gen. Marshall was awarded the Nobel Peace Prize. It has been amusing to me to read again and again what some historians have written about the Marshall Plan, that it was announced at “that famous commencement of 1947.”

Afterward, as the Fatigue Laboratory was being disbanded, I joined Woody Belding at the Climatic Research Laboratory in Natick, MA, and the Fatigue Laboratory was closed. But although this unique laboratory ceased to be, it is remarkable that, as observed by C. M. Tipton (16), “its stature has become enhanced, rather than diminished, with time.” The Harvard Fatigue Laboratory not only contributed to the Allied victory in World War II but also inspired the design of other laboratories and introduced a new approach to the investigation of human physiology.

ACKNOWLEDGMENTS

The author thanks Dr. Christopher Buresh (Department of Emergency Medicine, University of Iowa College of Medicine) for providing the support to prepare this article.

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).