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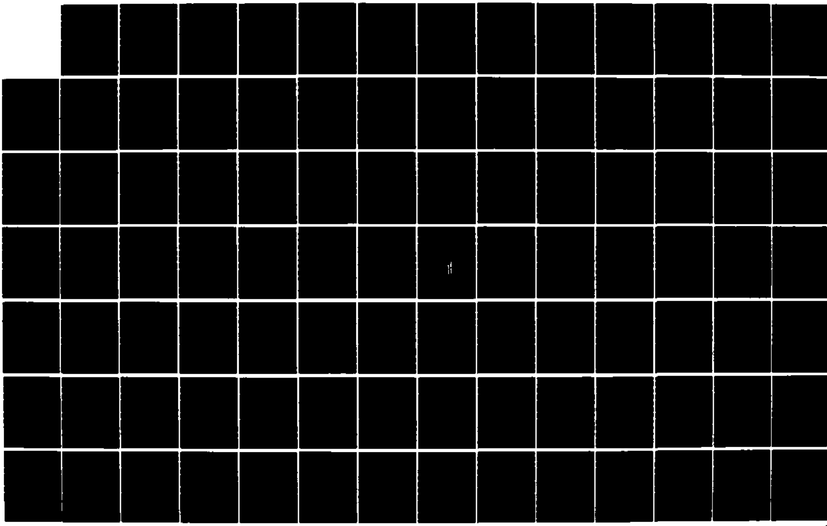

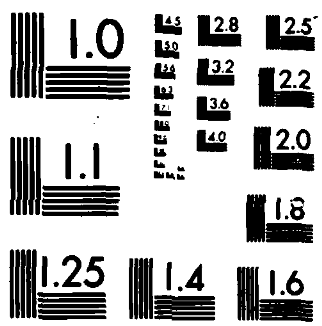

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THE UNIVERSITY OF WASHINGTON

THE EFFECTS OF ENVIRONMENTAL FACTORS ON WORKER PRODUCTIVITY IN THE CONSTRUCTION INDUSTRY

A REPORT SUBMITTED TO
THE FACULTY OF THE DEPARTMENT OF CIVIL ENGINEERING
IN CANDIDACY FOR THE DEGREE OF
MASTER OF SCIENCE IN CIVIL ENGINEERING

BY

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1. INTRODUCTION

Worker productivity is a foremost consideration in the construction industry. It captures, directly or indirectly, the interest of nearly everybody : contractors, owners, designers, lenders, insurers, consumers, fellow workers, transporters, suppliers, users, and the general public. Good worker productivity increases profits, decreases costs, moves materials, inhibits waste, conserves time, promotes good morale, increases motivation, decreases absenteeism, generates public good-will, promotes enthusiasm, minimizes injuries, and eases scheduling and planning.

Environmental conditions have a considerable impact on human performance and productivity in the construction industry in either an adverse or beneficial manner. Yet, very little has been written on the relationship between environmental factors and productivity as they relate to construction. The sparse information in the published literature generally reports the results of various laboratory experiments, performed under sterile, unrealistic conditions, and usually involving subjects other than construction workers.

Because of the dearth of information and because of the importance of this subject, it is necessary to address the environment-productivity relationship and to call it to the attention of those involved in the construction industry. In this report, seven environmental factors are discussed. These are altitude, noise, air ionization, temperature and humidity, the day-night cycle (shiftwork), vibration, and lighting. As every environmental condition affects human behavior in one manner or another, future research should examine the impact on productivity of other related factors such as dust, acceleration and deceleration, compression, the burden of special protective clothing apparatus, odorous environments, seasonal changes, and psychological effects of the worker including worry over domestic problems, fear of the jobsite or working conditions, over-exhaustion, and so forth.

Of course, there are other factors which affect worker productivity such as the project design; worker age, sex, stature, and skill; and management practices and techniques. However, this report focuses only on environmental conditions, and specifically only on those previously mentioned.

L.L. Farkas (40) notes:

> ...field men are generally compensated for the inconvenience of fieldwork done under unusual and uncomfortable conditions...(and) have turned in a creditable performance. But when such conditions continue, the men have a tendency to seek comfort and to spend time griping; even if their morale is not affected, the hardships will affect the work output.

Moreover, adverse environmental factors affect workers psychologically and physiologically over both long and short terms, and these, tethered to losses and delays resulting from injuries effect work output and efficiency even more. With advance knowledge and planning, such outcomes can be avoided.

It is in the best interest of contractors, personnel managers, schedulers and planners to realize the potential effect that the environment might have on future projects and to plan in advance the best methodology and personnel selection in making it work most effectively for them. Appendix A summarizes some of the least severe environmental conditions worthy of concern as they affect performance. In the following chapters are more detailed descriptions and recommendations concerning those factors previously identified.

2. ALTITUDE

GENERAL.

It is a well known fact that at high altitudes internal combustion engines, like those powering motor vehicles and heavy construction equipment, operate less efficiently unless certain modifications are made to the carburetor to ensure the correct ratio between quantity of fuel and air. This is because at the higher elevation, the density of air is reduced and consequently, there will be less oxygen in the cylinder. Since the oxygen ratio should remain constant, a lower quantity of fuel is delivered to the carburetor at the expense of engine power capacity.

It should be evident that man, likewise, is greatly affected by the sparse oxygen supply at higher altitudes. Like the internal combustion engine, operations at high elevations place a physical strain on the unsuspecting worker who is unequipped to handle the lower air density, and will be affected both physiologically and psychologically, i.e., worker performance will deteriorate in direct relationship to the altitude.

At an elevation of 10,000 feet, the atmospheric pressure is about two-thirds the amount observed at sea level. Since the gaseous makeup of the air remains constant with the percentage of oxygen at 20.94 percent, there will be only two-thirds as much oxygen in the air. Because the human body's demand for the precious oxygen does not change, the result is that a worker assigned a task at a high elevation will be required to breathe deeper and faster in order to satisfy the body's need for oxygen.

From the lowest point in the Dead Sea (altitude -1,292 feet) to the top of Mt. Everest (29,028 feet) there is a range of elevation of over 30,000 feet with man living or working primarily in the lower half of that range. Decompression (the decrease in the density of the air) increases with elevation and results in adverse consequences for the worker as the distance above sea level grows. For example, a deterioration in performance has been found at a height as low as 5,000 feet. At 10,000 feet a non-acclimatized person begins to experience shortness of breath. Unconsciousness may occur at an elevation of 20,000 feet (124) .

Acclimatization to high elevations is possible. After-all, some forty million people on this planet live at altitudes between 10,000 feet and about 17,000 feet above sea level, and it is well documented that some of the people with the greatest longevity live at such elevations in Russian and Equadorian villages. However, for an unacclimatized individual, "some investigators have suggested that generations (not days, weeks or years) of continuous existence at high altitude is required before performance equal to that of native residents is possible" (63).

Figures 1 and 2 illustrate the effect of oxygen and atmospheric pressure on human performance at various elevations. Oxygen is necessary for the generation of energy required to make the human body function. Figure 3 illustrates this.

It is unfortunate that the body does not store oxygen other than what is currently flowing in the blood stream. Muscles themselves can function for a short period of time without oxygen, however, some body parts, particularly those such as the brain and eyes which are part of the central nervous system, are sensitive to the oxygen depletion and would cease functioning without adequate oxygen. The brain in man is only 2 percent of the body's weight but accounts for about 20 percent of the total body oxygen consumption (150). Figure 4 is a schematic representing the flow of oxygen from the external atmosphere to energy production.

Of interest is an investigation by Jungmann (76) observing the course and duration of acclimatization to a relatively low altitude of 2,000 meters (6,562 feet) by a group of 27 individuals from the "lowlands". Figure 5 illustrates an immediate reduction in cardiac output and an increase in heartbeat rate in reaching the 2,000 m elevation. After two to three hours the increase in heart rate and cardiac output developed. The control group consisting of railwaymen and power station workers who lived

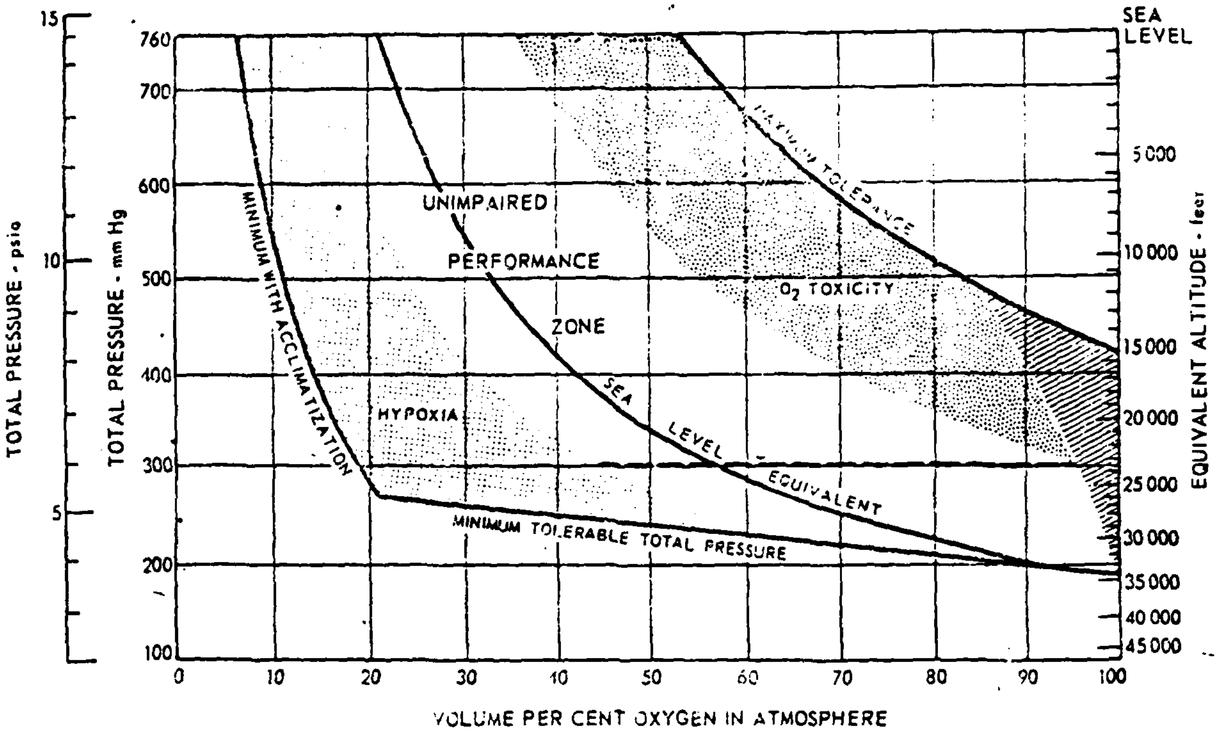


FIGURE 1

Effects Of Oxygen Volume And Atmospheric Pressure On Human Performance Based On Continuous Exposure For One Week Or More. Atmospheric air contains 21% oxygen by volume. At sea level, this leads to a blood oxygen saturation level of 95%. The Unimpaired Performance Zone, bounded by the shaded area indicates the range of variation that can be tolerated without performance decrement. Prolonged exposure to low oxygen levels lying to the left of the Unimpaired Performance Zone requires acclimatization. Acclimatization is accomplished by continuous exposure to successively lower pressures, with no intermediate return to higher pressures (93)(150).

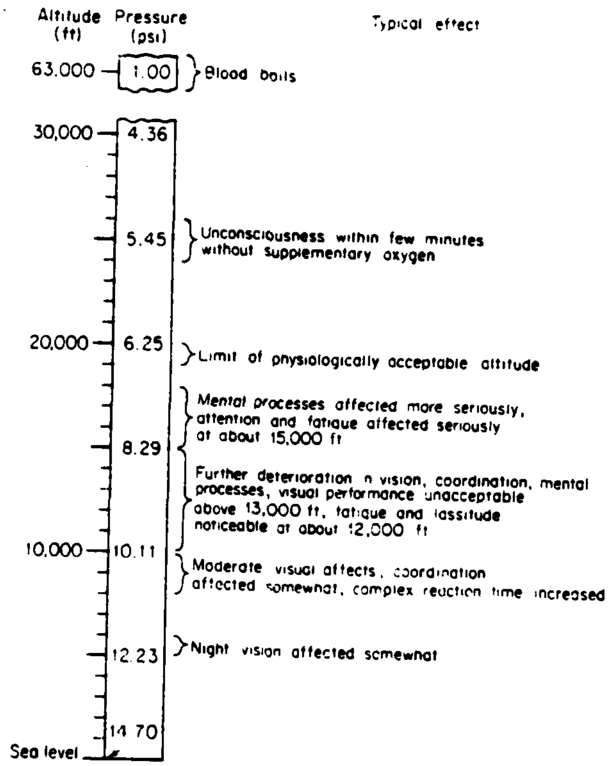


FIGURE 2

General Effects Of Hypoxia At Various Altitude Levels. Under normal conditions, the blood carries about 95% of its oxygen capacity but this decreases with increased altitude. At 10,000 feet, blood carries 90% of its potential oxygen capacity; at 18,000 feet, 70%; at 63,000 feet, the air pressure is so low that blood boils (98).

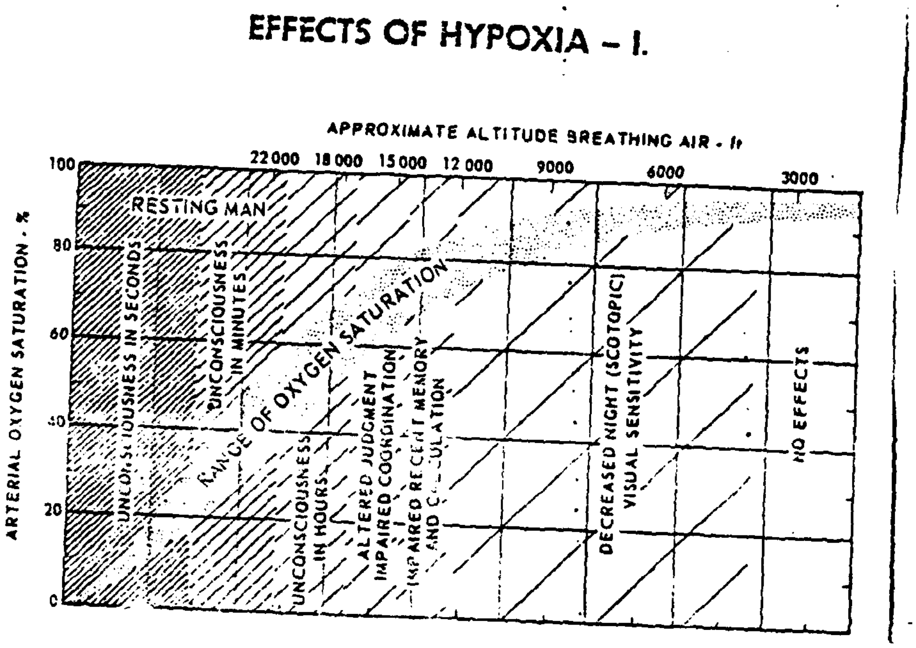


FIGURE 3

Hypoxia results from oxygen depletion in the human body. As altitude increases, progressive impairment occurs in the central nervous system, as indicated on figure 3 in the zones of increasing density. These changes occur in resting persons who are not fatigued or otherwise stressed. The oxygen saturation of arterial blood for resting persons is also shown as a range of saturation levels because temperature and pH influence the saturation values. Individual variability and time dependency are characteristic of these data (12)(100)(146)(150).

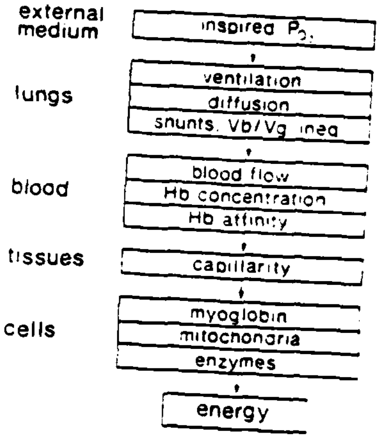


FIGURE 4

Schematic showing from above downward a flow of the path oxygen takes from the external medium to cell enzymes for energy production (13)(112).

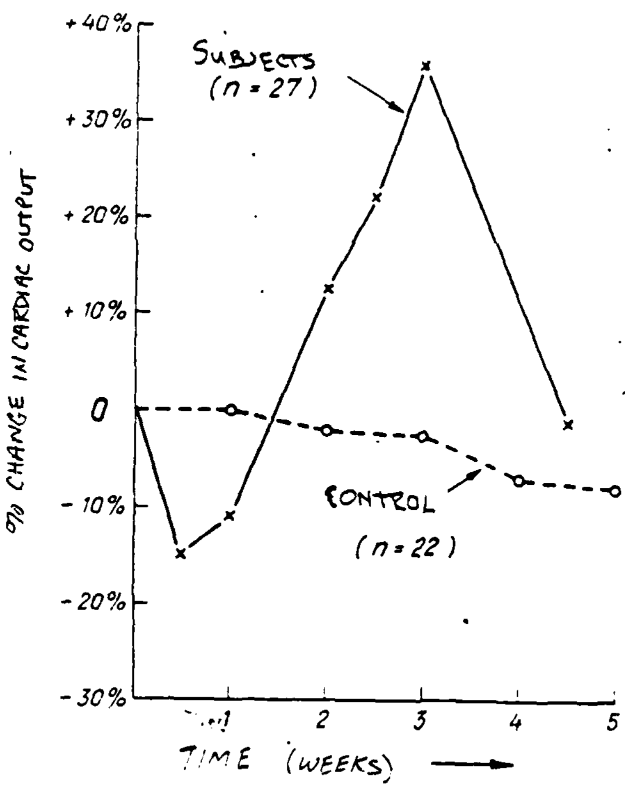


FIGURE 5

Changes In Cardiac Output On Transition To An Altitude Of 2,000 to 2,3000 m. Interrupted line: control group (acclimatized subjects). Adapted from (76).

and worked at the higher elevation showed no signs of these changes. During this initial 2-3 hours the subjects experienced some weakness and irregular heartbeats leading to disturbed sleep during the first evening. Some nausea and tendency to collapse was also evident.

By the end of the first week loss of body weight reached a minimum and gradually regained thereafter. Both heart rate and sporadic heartbeat patterns increased during the first and third weeks. Within the first three weeks, there were no changes in blood pressure except in subjects with hypertension who displayed a blood pressure drop. There were increased requirements for iron during the first two weeks with the maximum demand on the sixth and tenth days. Lung capacity diminished during the first few days and did not return to its original capacity for three weeks. The reason for the "turnaround" can be attributed to "compensating mechanisms" within the human body which tend to restore normal aerobic capacity. Briefly, these include: (1) an increase in lung capacity, (2) an increase in cardiac output, (3) a reduction in plasma volume which allows for (4) a gradual increase in the red blood cell and hemoglobin content in the blood, (5)an increase of myoglobin, the oxygen carrying pigment in the muscle, and (6) an enlargement of the blood vessels (vasodilation).

The experiment resulted in the following conclusions:

(a) Even at the relatively moderate elevation of

2,000 m (6,562 feet) there is some acclimatization to the lack of oxygen;

(b) Acclimatization is accomplished in stages and is not a steady, gradual process;

(c) It takes at least 3-4 weeks to reach maximum (but not total) acclimatization at the 2,000 m elevation level.

In an experiment by Shephard (134) where ten subjects were exposed to a simulated altitude of 18,000 feet for ten minutes the results were similar. The oxygen saturation showed a progressive decrease during the first ten minutes of hypoxia to about 75% of the original saturation. Initially, the pulse rose rapidly and then it plateaued at a value 40% above the initial rate. Some subjects showed no change in their respiratory rate while others fluctuated between normal and 60-70% above normal. The sporadic breathing was noted with several subjects. The respiratory volume of one minute increased progressively throughout the period of hypoxia, reaching a value of 40-50% sbove the normal resting level.

Another potential illness associated with working at high altitudes is high altitude pulmonary edema which may affect persons who ascend rapidly from sea level to high altitudes (above 9,000 feet). This condition is more pronounced when associated with physical exertion. Within a few days of arrival at the higher altitude, normally two to seven, the individual suffers breathing difficulties, coughs, and experiences fatigue. It occurs when high blood pressure in the lungs forces fluid out of the blood and into the lung tissue, triggering the development of pulmonary hypertension. Death may occur if the passage of oxygen to the blood becomes impeded (63). Children and teenagers are most likely to be stricken, however, it is also known to affect high altitude residents who return from a sea level visit and immediately take up strenuous physical work that they primarily performed on a routine basis (5)(69).

EFFECTS ON PERFORMANCE

Figure 6 illustrates those functions of the human body affected by high altitude. These include the brain, lungs, heart, stomach, glands, nervous system, and muscles. In addition, figure 7 illustrates construction productivity degradation as a function of altitude.

By the very nature of the symptoms noted in a person stricken by hypoxia (nausea, loss of breath, fatigue, rapid pulse rate), it is evident that a worker will not feel like working. Such a worker will be unenthusiastic and unmotivated, at least for the first few days until the natural "compensating mechanisms" take over and gradually acclimatize the body to the new environmental condition.

Aside from the physical ill-feelings, there are other repercussions experienced by an hypoxic individual. What these are, however, is complex and dependent upon a myriad of factors. For example, Phillips, Griswold and Pace (121)

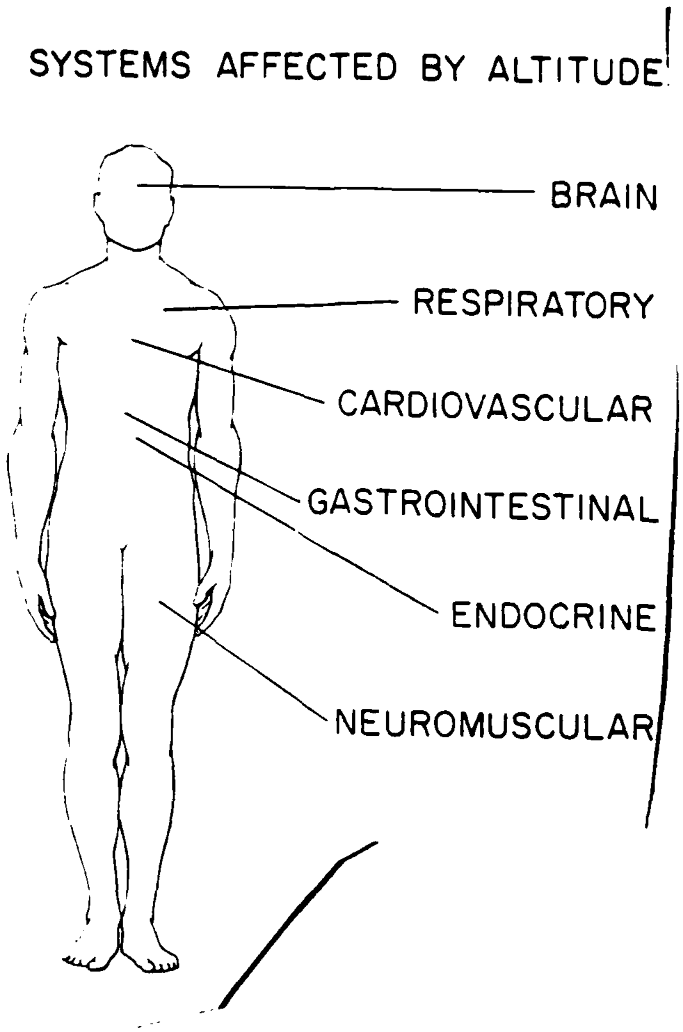


FIGURE 6

Systems Affected By Altitude

(48)

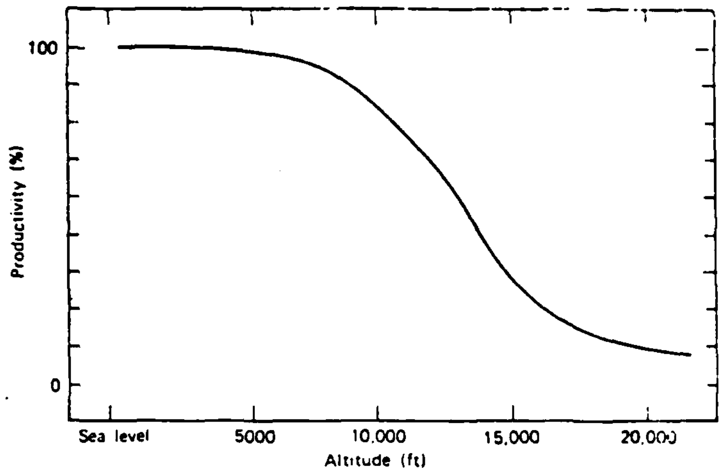


FIGURE 7

The Effect Of Altitude On Construction Productivity (63).

noted that in the case of "judgement tasks", the same degree of hypoxia could lead to impairment, improvement, or no change in performance depending upon the complexity of the psychological functions demanded by the task, coupled with the cognizant efforts by the subjects to overcome their physical ills.

In other experiments conducted by Ledwith (82) generally there is no impairment of performance at low stress levels. However, from sea level to 7,000 or 10,000 feet elevation there was a significant increase in reaction time and decrease in movement time. Hypoxic impairment of total response time was found at altitudes as low as 5,000 feet. Above 10,000 feet there was little further reaction time impairment, which the author theorized was the result of psychological stimulation by the subjects in response to feeling the hypoxic effect.

In studies of athletic performers it is concurred by experts that events of short duration (sprint-type) show no degradation resulting from the higher altitude. However, those of longer duration, generally more than two minutes, are adversely affected due to the limited amount of oxygen that can be supplied to muscle tissue. Training to achieve acclimatization was somewhat effective, but the level of performance never quite closed the gap between sea level and high level performances (5).

At very high, experimental altitudes (maximum 20,000 feet with 10 minute exposure by subjects) a decrease was noted in immediate memory and impairment in judgement. Attention decreased with hypoxia development (102) (134), there is a deterioration in handwriting (101) (134), mental fatique was noted (3) (134), and hand steadiness occurred in manual tasks (116) (134). Mood changes were also observed under these conditions. Shephard (102) (134) relates the following:

> Two types of subjects may be distinguished. In one...the hypoxia produced an initial stimulation of the central nervous system, with a decreased initial response time and increased error, but as the hypoxia becomes more severe, a 'depressive' type of reaction with increased initial response time and gross increase of error is observed. In the other type of subject...the 'depressive' type of reaction is present from the beginning, but becomes more marked with continued exposure to oxygen lack.

Although there have been no known studies relating the effects of high altitudes to performance specifically in the construction trades, it is safe to assume that the results of the previous observations are equally applicable to construction workers performing tasks at high elevations.

In summary, at high altitudes contractors may expect the following reactions on the part of their construction workers unless preventive measures are taken:

* Physical Reactions

* Deep and erratic breathing

* Faster heartbeat

* Weakness
* Disturbed sleep
* Nausea
* Loss of body weight
* Increased iron requirements
* Decreased lung capacity/loss of breath
* Unconsciousness (18,000 feet)
* Drowsiness
* Loss of appetite
* Decreased visual sensitivity
* Impaired memory and calculation
* Altered judgement
* Impaired coordination
* Slower reaction time
* Slower movement time
* Decreased attention to direction
* Deterioration of handwriting
* Mental and physical fatique
* Decreased hand steadiness in manual tasks
* Mood/personality changes

It is significant to repeat that although an individual never really becomes fully acclimatized to a new environmental condition, these symptoms will normally be most severe during the first few days of exposure and gradually decrease over the next four to five weeks, possibly more.

RECOMMENDATIONS

It is incumbent upon contractors who currently or intend to perform work at high elevations to recognize the symptoms listed in the previous section and to take precautionary measures to ensure an efficient and effective work effort.

It should also be realized that acclimatization is not totally effective:

> Tichauer (1963) measured the performance of groups of ten similar people performing similar machining work at sea level and at 13,500 feet. Work done by the man (sic) took almost twice as long at 13,500 feet. The amount of spoiled work increased from 1.5 percent at sea level to 9 percent at 13,500 feet. Unfortunately, no statistical tests appear to have been carried out on these results (124).

What, then, can a contractor do? The following measures are recommended:

(1) RECOGNIZE THE PROBLEMS SYMPTOMATIC OF HYPOXIA listed in the previous section.

(2) EMPLOY ON THE PROJECT WORKERS WHO ARE IN GOOD PHYSICAL CONDITION. Physical training at sea level has in itself been attributed to increased working efficiency. Under identical working conditions, a physically fit individual is found to have an increased myoglobin content, increased tissue capillarization, increased energy storage, and alterations in enzyme activity (124) which help to cope with oxygen deficiency.

(3) EMPLOY, AS MUCH AS POSSIBLE, WORKERS WHO ARE ACCLIMATIZED TO THE AREA; that is, those who normally live or work at the higher elevations. They will be able to work at higher performance levels than a counterpart arriving from sea level elevation.

(4) AVOID FREQUENT AND RAPID ASCENTS AND DESCENTS BETWEEN HIGH AND LOW ELEVATIONS. This will not only shorten the total time required to become acclimatized, but in addition, reduces the chances of becoming subject to pulmonary edema.

(5) AFTER ARRIVING AT A HIGH ALTITUDE (9,000 feet or more), A PERIOD OF REST AND INACTIVITY FOR 1 OR 2 DAYS SHOULD BE OBSERVED. Pulmonary edema has been directly linked to the performance of strenuous activity immediately upon undergoing an altitude change.

(6) ENSURE THAT WORKERS AND SUPERVISORS ARE TRAINED IN AND ARE AWARE OF THE POTENTIAL PROBLEMS ASSOCIATED WITH ALTITUDE. This may help in job crew selection through self-disqualification and avoid unnecessary risks by unknowledgeable workers.

(7) ENSURE WORKERS RECEIVE PHYSICAL EXAMS PRIOR TO JOB ASSIGNMENTS. Any interference with perfect health such as colds, asthma, intestinal problems, ulcers, diabetes, and insomnia may considerably affect tolerances to high altitudes. Workers with ear and sinus problems should also be avoided due to the decompressed air in the middle ear and sinuses.

(Note: Use of sinus decongestants may help, however recent evidence exists that continued use over long periods of time may become habit forming.)

(8) CONSIDER ALTERNATE MEANS OF ACCOMPLISHING THE CONSTRUCTION EFFORT, possibly substituting more numerous or larger pieces of heavy equipment for manpower. There may actually be a financial tradeoff, and in minimizing the manpower requirement, there will be a lesser chance of being faced with high altitude reactions.

(9) PERFORM AS MUCH OF THE WORK AT "NORMAL" ALTITUDE AS POSSIBLE. This is particularly true for mental tasks where judgement, sharpness, timing, and attention to detail are particularly vulnerable to hypoxic conditions.

(10) STRICTLY FOR EMERGENCY REASONS, MAINTAIN AN AMPLE SUPPLY OF OXYGEN ON THE JOBSITE. Many of the hypoxic and edemic symptoms are sharply reduced with the inhalation of oxygen.

It is recognized that many contractors will never have the opportunity to work at very high elevations. However, a contractor can never be certain of the altitudes at which future projects will be performed. Thus, it is an important that contractors be aware of the altitude effects on worker performance.

3. AIR IONIZATION

GENERAL

Very little is known about the effects of charged ions in the air on human performance. What is known is that in the 1950's manipulation of the ion ratio was considered to be such a cure-all, such a panacea for healing all illnesses from constipation to cancer, that the federal government found it necessary to regulate the advertising and distribution of commercial ionizers until such time that additional research could be performed on ionizing effects. The consequence has been a discouragement of legitimate scientfic interest on the subject with only scattered research actually performed since that time (79).

The recognition of the ionization effect on man actually dates back to Hippocrates in the fifth century B.C. Although he did not know the exact cause, Hippocrates wrote that "northern winds occasion disorder and sickness," meaning that people are sensitive to weather. It wasn't until the turn of the twentieth century when the phenomenon was associated with electrical charges in the air. Being "under the weather" does, in fact, hold some truth.

Air ions are molecules of the common atmosphere gases which assume a negative or positive electrical charge. When they are created, there are an equal number of positive and negative ions and they tend to pair up and neutralize one another. Charged particles are formed when energy produced by natural causes, such as radioactive elements from the earth's crust, solar rays, lightning discharges or ultraviolet radiation (24), cause a gaseous molecule to lose a negatively charged electron. The displaced electron attaches to an adjacent molecule becoming a negative ion and the original molecule becomes a positive one.

Because of the earth's negative charge, the negative ions are generally repelled by it. In addition, because the negative ions are smaller and faster, they tend to crash into and remain on physical objects, leaving an abundance of positive ions within the air. *In a room*, the walls will have the negative charge and the air will contain the positive ions. The result is a natural positive to negative ratio of 1.2 to 1 (79). Near waterfalls, on the otherhand, the positive ions tend to fall to the ground with the water, leaving an excess of negative ions in the air (as many as 37,000 per cubic centimeter of air) (124) (33).

In normal clean air over land, there are from 200 to 4,000 charged ions per cubic centimeter of air, depending upon the weather conditions (24) (79). The same cubic centimeter has about 10 million trillion uncharged particles (80). In addition to the natural causes of charged particles, man has unknowingly added a number of others. Metal structures, such as buildings and bridges, reach high temperatures in the heat and produce large amounts of predominately positive ions. Open flames - even a lit match - generate floods of ions. High voltage lines, a pounding surf and a building demolition all contribute to disassociate air molecules into ions. Static electric charges such as those caused by wearing certain synthetic clothing, moving plastic sheets in dry air or even the operation of mechanical equipment likewise result in the phenomenon.

It is known that exposure to ionized air has a considerable effect on human behavior. Because the construction industry is so much a part of creating the "man made" ionization phenomenon and because of the exposure that workers continually have to ionized environments, recognizing the potential ionizing effects on workers and taking efforts to assist or decrease them should be of interest.

PERFORMANCE

Unlike hypoxia and other environmental effects, ionization is not believed to cause any major physiological problems in human beings. Instead, charged ions have been likened to drugs..."uppers" and "downers", because of their effect on mood, motivation and performance as caused by reactions within the brain.

The theory is that negative ions make us feel good, while a large proportion of positive ions have the opposite effect. There is mounting evidence that charged ions do actually cause changes in the brain by altering the quantity of the neurohormone SEROTONIN (5-HT). This chemical has been linked with the function of the endocrine glands and central nervous system which, in turn, affect other basic physiological processes such as sleep, the transmission of nerve impulses and the development of mood. Reduction of the 5-HT levels in the brain by negative ions has a tranquilizing, almost euphoric action, while an increase caused by a high ratio of positive ions in the air, has been associated with general irritability, depression and lethargy.

Certain conditions create higher levels of positive ions than are found under normal conditions. For example, there is a sharp increase of positive ions in the air the day prior to the arrival of warm, dry winds across large land masses such as the Sharov of Israel, the Santa Anas of Southern California, the Chinook of Canada, and the Foehn of Switzerland and Central Europe (140)(144).Prior to the arrival of these winds, observations of personal irritability, depression, discomfort, tension, insomnia, migraines, lassitude, breathing difficulty, and nervousness were made. In fact, these "devil winds" have been blamed for outbreaks of violence and suicide among the populations exposed to them (36) and people often compensate for their effects: judges are more lenient; surgeons postpone elective surgery, and teachers expect unruliness from their students (80). So frequent is the malaise that Israeli scientists have dubbed the phenomenon "Serotonin Hyperfunction Syndrome" or "Irritation Syndrome" (79).

The effects of ions on human behavior have received a moderate amount of attention since the fifties and have been observed, under laboratory conditions, in terms of sensation, activity, learning, comfort and well being, vigilance reaction time, mood and performance. Laboratory tests have progressed from microorganisms through human beings and have resulted in the following conclusions:

* Ions are biologically active, affecting all living matter;

* Depletion of ions in the air may increase a person's susceptibility to illnesses;

* An increase in ions- particularly negative ones- may be useful in the treatment of burns and respiratory diseases;

* Urban conditions, including smog, pollution, dense populations, and air conditioning, decrease the negative to positive ion ratio (80).

Scientists have found that some 10 to 12 hours before the Sharov winds and accompanying humidity and temperature change, the total number of ions increased from 1500 ions per cubic centimeter to 2600 ions per cubic centimeter and the ratio of positive to negative ions jumped from 1.2 to 1.33. The shift in ion ratio coincided with the onset of nervous and physical symptoms in those sensitive to the weather, leading to the conclusion that the symptoms are not coincidental and happenstance. Further, the scientists found that the victims of irritation syndrome experienced relief when treated with negative ions or with drugs that interfered with 5-HT production (79).

Experiments in Russia found that high concentrations of air ions inhibited growth of disease causing bacteria and reduced the number of microorganisms normally found in the air (80).

Experiments on mice and rabbits showed that ions directly effect the lining of the trachea, the section of the respiratory system between the lungs and the mouth, and also affected the animals' ability to respond to respiratory disease. Negative ions improved the situation while positive ions impaired it. (80)

Serotonin was linked to air ionization when it was found that animals exposed to positive ions developed diarrhea, muscle spasms, and breathing problems. Because 5-HT results in similar effects, it was theorized that positive ions cause the release of 5-HT from the brain while negative ions increase its oxidation, thus removing it from the body sooner.

The theory was confirmed later by animal laboratory experiments.

Several tests have been conducted to examine the effects of ions on human behavior. Tests in India have shown that artificially increasing negative ions produces increased cheerfulness and alertness while decreasing errors and illnesses (62). In a Swiss bank, 33 employees were exposed to negative ions in an office encironment for 30 weeks resulting in a 94% decrease in lost work time (80). In Oregon schools there was a 17% decrease in absenteeism at one school and 27% at another when negative ions were emitted into the atmosphere (80). Investigators in Japan found that if temperature, humidity, and carbon dioxide levels were held constant but ion levels were reduced, subjects perspired and complained of depression (80).

Ionizing is also being investigated as a means of treating medical ills. Ions have been shown to pass their charges on to cough and sneeze particles causing the infectous droplets to fall harmlessly out of the air. Negative ion therapy has been used to treat over 200 burn patients at the University of Pennsylvania. A majority of patients reported relief within 10-15 minutes after exposure to the negative ions (80).

Learning has also been shown to be influenced by ion exposure, and experiments on rats demonstrated that fewer errors were made when running through mazes when the air was enriched with both positive and negative ions, with negative ions improving performance to a greater extent.

Hawkins and Barker (62) have shown that negative ions and positive ions also affect the circadian rhythm. Negative ions appear to flatten the rhythm's amplitude. In an experiment, control subjects showed a rising level of performance between 0900 hours and 1600 hours with a subsequent decreasing level thereafter until 2100 hours. Subjects exposed to negative ions maintained a high level the entire period, including the evening hours. Those exposed to positive ions showed a more rapid worsening of performance and to a greater extent.

In the United States the study of ions has received most support from employers concerned with the effects of ions on their employees. At the end of a working day a typical office may contain as few as 20 negative ions and 34 positive ions per cubic centimeter of space, compared to some 4000 ions found in a cubic centimeter of fresh, unpolluted air on top of a mountain (79) (80). Aware of the possible ramifications of high density spaces, pollution, static electricity , and mechanical equipment on ion production or reduction, employers are interested in achieving all the beneficial aspects in attempting to improve motivation, attendance, productivity, and quality of output.

Contractors, too, should be interested in maximizing negative to positive ion ratios and minimizing positive to negative ion ratios. In substituting the positive ions with negative ions, worker output will increase, contract time will be reduced, quality of workmanship will improve, and increased profitability will be realized.

No known research has directly linked the effects of air ions with the construction industry. However, from the above discussion, it is evident that the following descriptors can be used to describe the general effect ions have on human behavior, including that of construction workers:

POSITIVE IONS	NEGATIVE IONS
breathing difficulty	less anxiety
violence	learning facilitation
undesireable	tranquility
headaches	reduced infection
nervousness	burn treatment
diarrhea	mental/physical efficiency
unruliness	comfort
muscle spasms	cheerfulness
sleeplessness	alertness
irritability	decreased errors
stomach upset	elation
perspiration	beneficial
depression	energy
discomfort	euphoria
lassitude	
enervation	
aggressiveness	
tension	
nausea	
apathy	
fatigue	
sedation	

RECOMMENDATIONS

Because of the many uncertainties and the sparse research done on the effects of ions, artificial ionization should be undertaken with caution. The purpose of this discussion is to advise contractors of routes for potential project efficiency and effectiveness and pitfalls to be avoided. Accordingly, the following recommendations are provided for consideration:

(1) WET DOWN WORK AREAS AS MUCH AS POSSIBLE. Demo-

lition, dust, excavation, etc., are known to generate excessive positive ions;

(2) PROVIDE CONSTANT SPRAY AND/OR EMPLOYEE SHOWERS, IF POSSIBLE. Broken water molecules are known to provide negative ions, providing a rejuvenating effect;

(3) HUMIDIFY WORKING SPACES. Humidity generates ions and will eliminate static electricity;

(4) WEAR CLOTHING AND USE MATERIALS NOT PRONE TO PRODUCE STATIC ELECTRICITY. Static electricity produces a negative charge around a person, repelling the beneficial negative ions and attracting the undesireable positive ones;

(5) ELIMINATE OPEN FLAMES AND LIMIT SMOKING AWAY FROM THE IMMEDIATE WORKSPACE. These, too, increase the undesireable positive to negative ion ratio;

(6) ATTEMPT TO USE SHIELDED MECHANICAL AND ELECTRICAL EQUIPMENT designed to provide minimal electromagnetic current.

Even if the above recommendations are not feasible for a particular construction job, it behooves the contractor to be aware of the phenomenon in the event that the symptoms among workers become commonplace and a possible reason for the trend is sought.

4. TEMPERATURE AND HUMIDITY

GENERAL

Human life can be maintained in climates ranging from extreme, furnace-like heat to Arctic cold. In the former, the problem is to maximize heat loss, while in the latter, maximizing heat generation and minimizing heat loss are of primary importance. The critical variable, in any case, is exposure time which may range from a few seconds to a lifetime.

Goldman (50) relates that man's ability to stand extremely hot air temperatures was first noted in 1760 when two French scientists were unable to measure the inside temperature of a hot baking oven because the thermometers would immediately cool upon removal. A girl tending the oven offered to climb inside to read the thermometer, at which time she remained inside for twelve minutes at a temperature of 149°C (300°F). As recently as 1949, man's natural tolerance to dry heat has been charted at 104°C (220°F) and 24 minutes at 115°C (240°F). Goldman cautions, however, that when humidity to saturation is added, tolerance is limited to about 50°C (120°F).

Because of the variables involved in providing the sensation of heat on the exterior of the body (temperature, radiation, wind, humidity) a common unit of measurement, Effective Temperature (ET), is normally used. It is a scale of subjective comfort based on the combination of the climate variables into a single value. An ET cf 70° is defined as air at 70°F fully saturated with water vapor, with next to no air movement. Dry bulb temperature (T_{DB}) is the normal reading taken directly from a thermometer not taking into account humidity or wind, while wet bulb temperature (T_{WB}) considers humidity (100% saturated) but not the effects of wind. It gives a direct measure of the lowest temperature which the skin can reach by evaporation.

Relative humidity is the ratio of vapor pressure of water in air to vapor pressure in saturated air at the same temperature. It affects both feelings of comfort and warmth at high temperatures. Relative humidity in the 35 - 65% range is usually desired (105). The National Institute for Occupational Safety and Health (NIOSH) has defined a hot environment as one in which the temperature, humidity, radiation and wind speed combine to create a wet bulb temperature of 70° or greater.

Other measures of temperature are also used: a calorie is the quantity of heat required to raise the temperature of 1 gram of water 1°C. The cooling power of man is expressed as calories per square meter of body surface area. The "reference man" for calculating body surface area weighs 70 kg (154.7 lb), has a height of 174 cm (68.6 in) and has a surface area of 1.8 square meters (19.4 sqft).

The effects of heat or cold on human exposure depend on numerous variable factors including air temperature, humidity, air movement, radiant heat, rate of work, degree of acclimatization, the age and physique of exposed individuals, and the amount and type of clothing worn (84). Any or all of these affect the tolerance that man has to extreme temperatures which in turn, affect the rate of work, quality of work, and overall performance exercised by individuals. Because of the nearly intolerable hot or cold working conditions in which construction workers are often required to work, this topic is of particular interest to contractors who wish to maintain the highest possible productivity without jeopardizing worker health and efficiency.

HEAT

Through common knowledge and experience one has come to realize that with the arrival of sudden, hot weather, the ability to perform work that is easily done in cool temperatures is impaired. Within a short period of time of working through the heat wave, there is a gradual return of the ability to work with little or no discomfort as the worker becomes acclimatized to the new environmental temperature condition.

Women are considered to tolerate heat less well than men, but overall both sexes develop acclimatization rather well. The fitness of the individuals play an important role, but the amount of strenuous work given to a worker, male or female, relative to their body size is equally important. A person of relatively small stature or work capacity obviously will be using more reserve capacity at a given work load than will a larger, stronger person and this will be reflected by such physical identifiers as pulse rate, body temperature, breathing capacity, and cardiac output.

Heat does, in fact, significantly affect performance. Investigations of the tinplate, iron and steel, and glass bottle industries reveal a seasonally related productivity output variance of an average of 10% and in some cases, as much as 30%. Productivity in weaving and coal mining falls off when temperatures rise above 75°F. Further, the number of reported accidents increased with temperatures below 55°F and above 75°F (120).

The results of a 1947 study by Mackworth (95) (120) showed that the maximum physical output of a young, fit, heat acclimatized man decreased significantly at an effective temperature of 86°F. When the effective temperature reached 100°F output was reduced to two-thirds of that achieved at the 66° effective temperature. Similarly, a 1946 study by Caplan and Lindsay of Indian miners showed work output to decrease significantly when the effective temperature was raised to 85°F (86) (120). A 1959 study of South African gold miners found that as temperatures increased from 81 to 84°F the performance of the acclimatized miners declined by 4%, and then, work output fell more quickly to about 50% of normal output in a climate of 93°F (120).

The impact of heat appears to be most pronounced for those who are working their hardest at a physical task or are unsuccessfully straining to perform a highly skilled task. As a result of its internal, metabolic activity, the human body continually generates heat as a by-product. With the exception of actual work output, essentially all enery expended by the body is converted into heat. For example, a resting adult male ganerates 1 kcal/min. of heat; in performing non-strenuous sedentary activities, he generates 1.5 to 2.0 kcal/min.; in performing moderately physical activities, 5.0 kcal/min.; and in performing extremely heavy work, up to 20.0 kcal/min. (35). Table 1 lists the hourly energy expendi-

Form of Activity	*Calories per hour*
Sleeping	65
Awake lying still	77
Sitting at rest	100
Standing relaxed	105
Dressing and undressing	118
Tailoring	135
Typewriting rapidly	140
"Light" exercise	170
Walking slowly (2.6 miles per hour)	200
Carpentry, metal working, industrial painting	240
"Active" exercise	290
"Severe" exercise	450
Sawing wood	480
Swimming	500
Running (5.3 miles per hour)	570
"Very severe" exercise	600
Walking very fast (5.3 miles per hour)	650
Walking up stairs	1100

TABLE 1

Energy Expenditure Per Hour During Different Types Of Activity For A 70 Kilogram Man (58).

ture of a 70 kg (154.7 lb) man performing various types of physical activity. Note that walking up stairs requires 17 times as much energy as lying in bed and that in an 8 hour day, a carpenter burns up nearly 2000 calories.

The body continually tries to remain in a state of temperature equilibrium with the environment and adjusts itself to the everchanging exterior. Even the casual observer realizes that as the temperature cools from the norm, the (1) skin becomes cool, (2) blood is routed away from the skin - surface and more toward the central body core, (3) "goose bumps" appear on the skin, increasing its insulation power, (4) the core temperature (rectal) normally rises, (5) shivering occurs, and (6) there is a lowered blood pressure. As the environmental temperature warms from the norm, the observer's (1) skin becomes warm, (2) more blood is routed to the outer skin surface, (3) the core body temperature drops, (4) shivering may occur, and (5) sweating is likely to occur.

In reality, what occurs is that (1) a large blood flow is directed to the working muscles, providing oxygen to them and dissipating heat away from the central core; (2) the increased blood flow to the skin surface cools the blood (similar to the way an automobile's radiator cools water) and supplies the sweat glands with water, and (3) flow through the liver and other internal organs transfer water from them to the sweat glands and other working muscles.

The body loses heat to the atmosphere by four processes:

evaporation, radiation, conduction and convection. Loss of heat by radiation means loss in the form of infrared heat rays. All mass in the universe, not at absolute zero temperature, radiates such rays. Just as heat radiates from the human body, it also radiates from wall, furniture, carpeting, and all other matter towards the body. The net result depends on whether the human body is warmer than the surroundings (the body loses more heat than it receives) or whether the surroundings are warmer than the human body (the body receives more heat than it gives off).

The body loses a little heat by conduction to objects such as furniture, and somewhat more, directly to the air. Here, heat is passed on from one molecule to an adjacent one as they are in contact with one another.

Convection involves the removal of heat from the body by the movement of air. Convection almost always occurs around the body because of the tendency of air immediately surrounding the skin to rise. Heat loss occurs much more rapidly when there is a breeze and the layer of air immediately adjacent to the skin gets replaced by new air more rapidly than normal. Figure 8 illustrates the importance of this phenomenon.

Evaporation is one of the most effective ways of cooling the body, and in the event where the environmental temperature is greater than that of the body, is the <u>only</u> means by which the body can rid itself of heat. Air movement

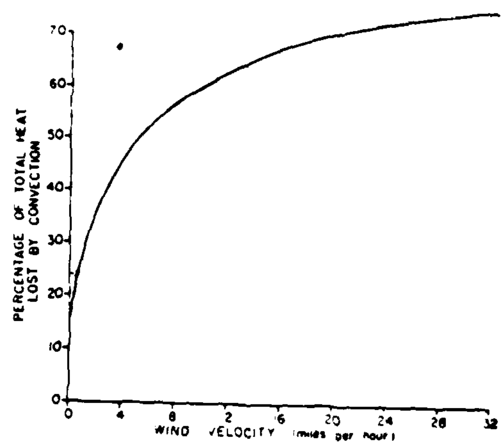


FIGURE 8

Percentage Of Total Heat Lost Through Convection As A Factor Of Wind Velocity (58).

again aids in the evaporative process by replacing the zone of air adjacent to the skin layer. The thickness of the air layer surrounding the body provides significant insulation between the skin surface and the environment. Goldman(50) uses the example of occupants of a turkish bath with the air saturated and at 50°C (122°F). If a fan were placed in the bath penetrating the air layer, all would flee as the 50°C moist air reached the skin. Man's tolerance is only 45°C (113°F) under these conditions.

Figure 9 illustrates each of the four mechanisms by which heat is removed from the body and figure 10 shows the percentage of heat lost by each process at different temperatures.

When an unacclimatized person performs a moderate amount of work in a hot environment (walking 3½miles per hour for 1 hour at 120°F) the individual will first experience severe discomfort. Dizziness, nausea and collapse may occur, accompanied by high body temperature, rapid heart rate, high skin temperatures and inadequate quantities of sweat. However, after performing the work for four to seven days, the worker's ability will be improved as well as the beforementioned physical conditions. It is evident that the worker has become acclimatized. The physical improvements are all indicative that the body's "early warning system" has taken effect: reduced body temperature reduces the risk of heat stroke; lower heart rate signifies less cardiac strain; increased

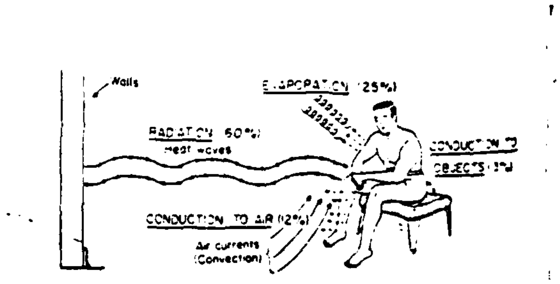


FIGURE 9

Mechanism Of Heat Loss From The Body (58).

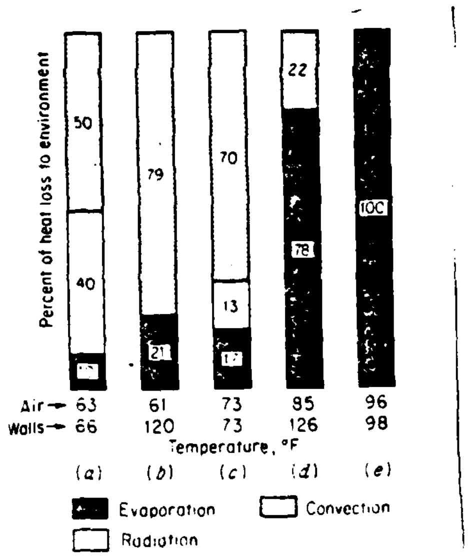


FIGURE 10

Percentage Of Heat Loss To The Environment By Evaporation, Radiation, And Convection Under Different Conditions Of Air And Wall Temperature (98).

sweat production makes available more water for evaporative cooling; and lower salt content reduces the depletion of the storage of salt in the body (7).

Bass (7) describes the acclimatization process in the following manner:

(a) It begins with the first exposure, progressing rapidly, and is well developed in 4-7 days;

(b) It can be induced by short, intermittent work periods in heat (2-4 hours daily). Inactivity results in only slight acclimatization;

(c) Subjects in good physical condition acclimatize more rapidly amd are capable of more work in the heat. Good physical conditioning by itself does not result in acclimatization;

(d) The ability to perform "maximal" work in the heat is attained quickly by progressively increasing the daily work load. Strenuous exertion on first exposure may result in a disability which will impair performance for several days;

(e) Acclimatization in severe conditions will facilitate performance at lesser conditions and provide "partial" acclimatization to more severe conditions;

(f) The general pattern of acclimatization is the same for short severe exertion as for moderate work of longer duration;

(g) Acclimatization to hot, dry climates increases performance ability in hot "wet" climates and vice versa;

(h) Inadequate water and salt replacement can retard the acclimatization process;

(i) Acclimatization to heat is well retained for about two weeks of non-exposure, after which retention is dependent on the individual. In two months, most of the acclimatization is normally lost, however, those in good physical condition may retain the acclimatization better than others.

It is amazing that the temperature of the body interior remains almost exactly constant, within $\pm 1^{\circ}F$ daily, except in the case of an illness. Under ideal conditions, the nude person can conceivably be exposed to temperatures as low as 55-$60^{\circ}F$ or as high as $150^{\circ}F$ and still maintain an almost constant internal body temperature (58).

A rise of body temperature to only $99.1^{\circ}F$ ($37.3^{\circ}C$) reliably impairs performance. A rise to $101.3^{\circ}F$ ($38.5^{\circ}C$) makes a person uncomfortably hot and aroused, possibly even improving his efficiency at a task. Collapse or heat stroke occurs before the body temperature rises much above 105°F (40°C) (2).

NIOSH has stipulated that a worker's deep body temperature shall not be permitted to exceed 38°C (100.4°F), the beginning of the so-called "environment divergence zone" (EDZ), where a relatively small increase in environment heat will cause a substantial increase in deep body temperature (75). Figures 11 and 12 illustrate this.

In a vigilance experiment by Bell (8) there was no evidence that environmental temperature directly affected performance; however, it was noted that both visual and audio performance deteriorated with increasing body temperature. At five different exterior temperatures ranging from 76°F to 116.5°F, the average increase in oral temperature was 2°C with an average duration of 45 minutes and terminated by imminent collapse.

As the body temperature rises, more blood goes to the skin to be cooled through radiation and convection. The skin appears pink and flushed and the person sweats considerably. The heart rate increases, even if the subject is sitting. This is symptomatic of heat stress and is associated with a failure to respond to important events during the extended performance of normally routine tasks. (See figure 13). In the bottom curve, the workers are doing the equivalent of 400 kilocalories of work per hour or the same as walking 4

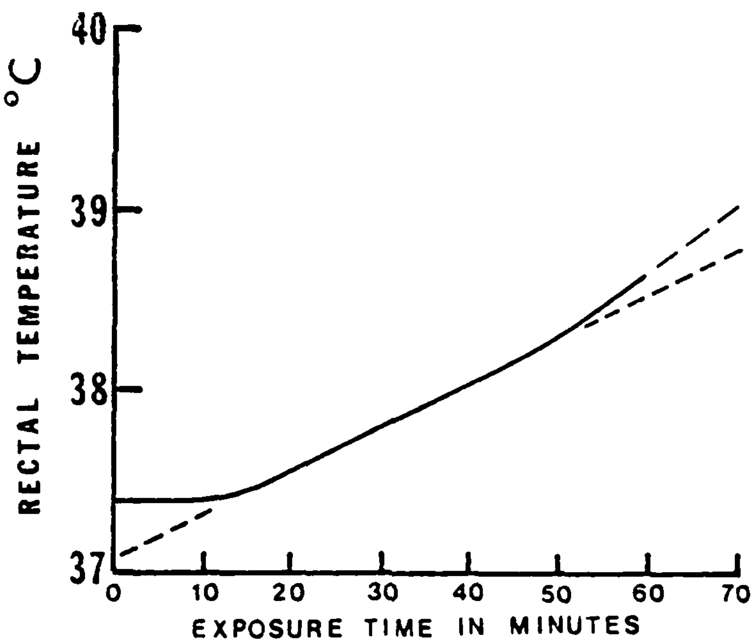


FIGURE 11

Rectal Temperature Of One Subject Exposed To Heat. Note the heightening of the increase rate after 50 minutes when the rectal temperature exceeds 38.2° C (79)(88).

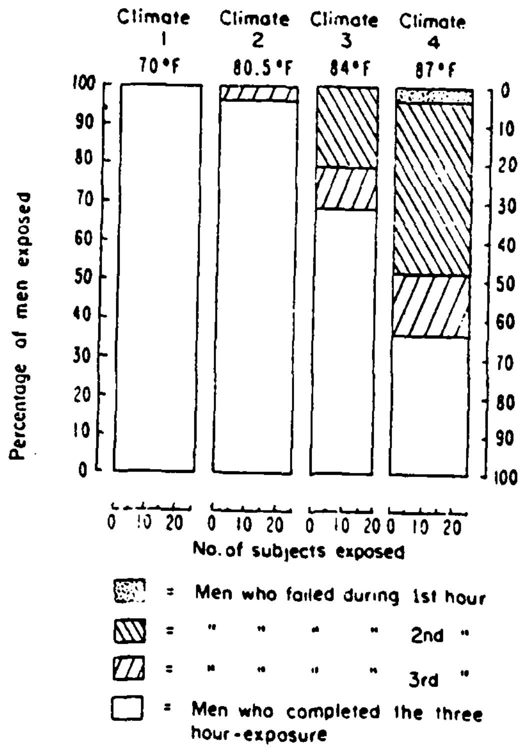


FIGURE 12

The Numbers Of Men Who Reached A Deep Body (Rectal) Temperature Of 102.5^{o}F And/Or A Pulse Rate Of 180 Beats/min While Working At An Energy Expenditure Of 300 kcal/hr Continuously For 3 Hours In One Of Four Different Climates With Effective Temperatures Of 70, 80.5, 84, And 87^{o}F (75)(85).

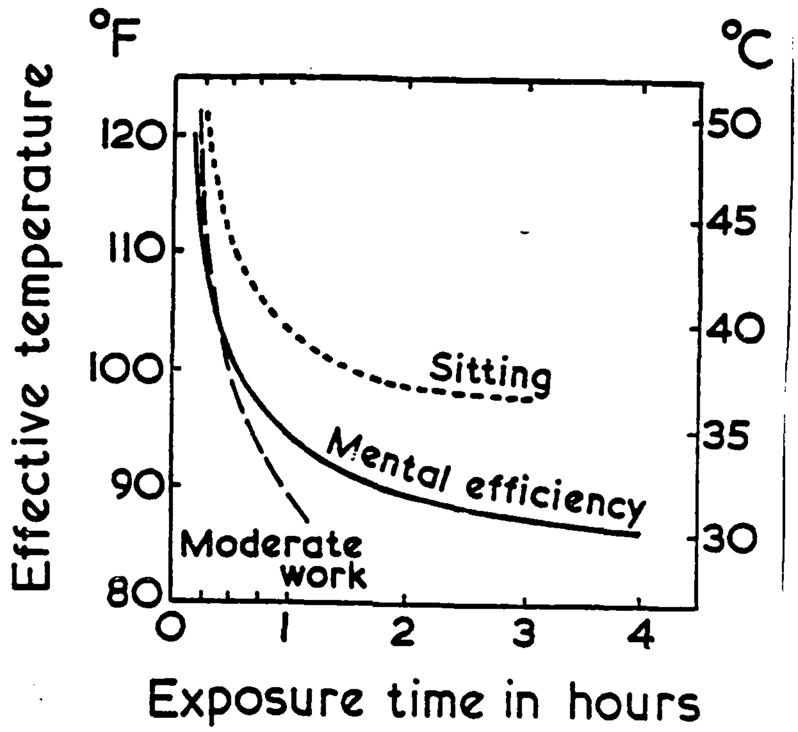


FIGURE 13

Critical Combinations Of Effective Temperature And Exposure Time. The upper dotted curve shows the mean physiological limit for doing a moderate amount of work. Most people cannot tolerate longer exposures than those shown. The middle unbroken curve shows the limit for efficient performance. Points on or up to the line have produced reliable drops in efficiency (124)(155).

miles in an hour on a level floor.

Under normal conditions 5% of the blood flow is directed to the skin surfaces, but during the heat adaptive process, the amount is increased to nearly 20%. A decrease in blood pressure results and less blood flows to other organs. To compensate, the heart rate increases to pump more blood. If an insufficient amount still flows to the brain, heat exhaustion occurs as indicated by extreme fatique, nausea, and dizziness. Decreased performance results, due to a deficiency of good, steady oxygen supplied to the working muscles as a result of the decreased blood flow (131). Figure 14 shows the effect of temperature and humidity on the muscle oxygen supply and Figure 15 illustrates how heat stress can effect work performance. It emphasizes how humidity coupled with temperature limits performance capability. In this example, 16 army soldiers with 20 lb backpacks marched at 3 mph for 4 hours.

There is a maximum amount of heat a body can lose even with maximum sweating. When the hypothalamus (or heat regulating part of the brain) becomes too hot, its heat regulating ability is stifled and sweating totally ceases. As a result, the internal heat production self-perpetuates so rapidly that at 107-110°F the dissipation of heat is no longer possible. Brain functions are disturbed and confusion, disorientation, delirium and convulsions are likely to occur. Body temperature will continue to rise rapidly, and death will occur if this

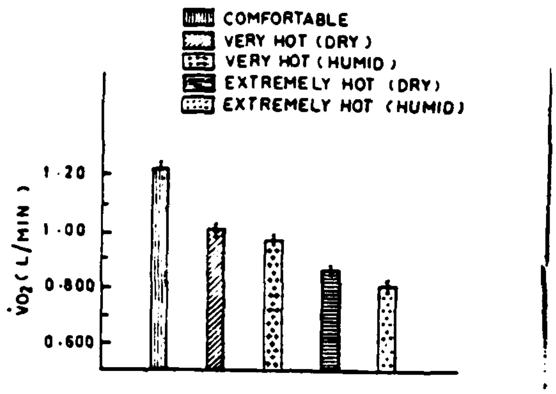


FIGURE 14

Effect Of Very Hot (dry and humid), And Extremely Hot (dry and humid) Climates On Steady State O_2 Consumption In Submaximal Fixed Work (600 kgm/min)(57).

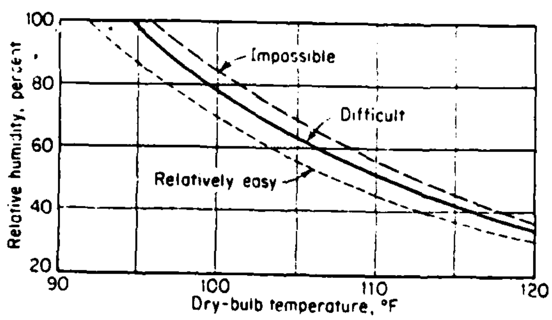


FIGURE 15

Relative Difficulty Of Performing A Marching Task Under Various Temperature And Humidity Conditions. The three lines show the conditions under which the work was easy, difficult, and impossible, respectively (98).

condition remains unchecked by artificial medical means; this is heat stroke.

A person exposed to hot weather for several weeks sweats progressively more and more profusely with time. At first, sweat will be at the rate of 1.5 liters per hour; after 10 days, 2 times that amount; and within 6 weeks, about 2½ times as much. Figure 16 graphically represents this increase.

Undoubtedly, the most serious threat to man's wellbeing under conditions of high temperatures is dehydration. Sweat losses are so high that compensation cannot be relied upon by drinking water alone. Therefore, the duration of steady, hard, uninterrupted work should be limited with the additional stipulation that ample supplies of cool water be made available and consumed. Failure to replace water lost by sweat can lead to serious dehydration in 3 to 4 hours (84). Dehydration not only reduces heat exchange by evaporation but also directly affects the plasma volume of the blood. Accompanying the increased heart rate resulting from lower blood volume is an increase in internal temperature verifying the inadequate heat exchange to the environment. Adolph (128) calls the resulting characteristics "dehydration exhaustion" and symptoms include decreased work output, drowsiness, faintness, breathing difficulty, dry mouth and restlessness.

In hot conditions, light and loose clothing permit

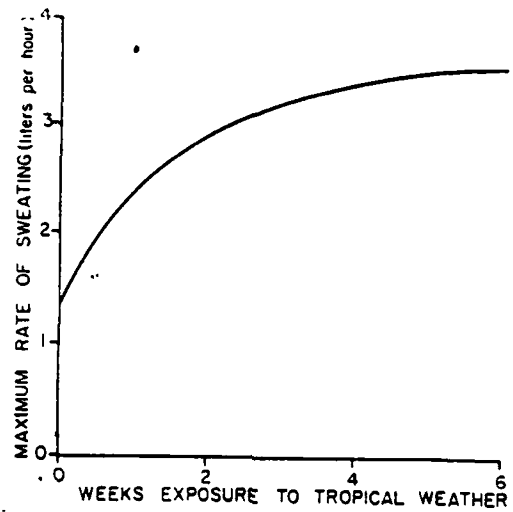


FIGURE 16

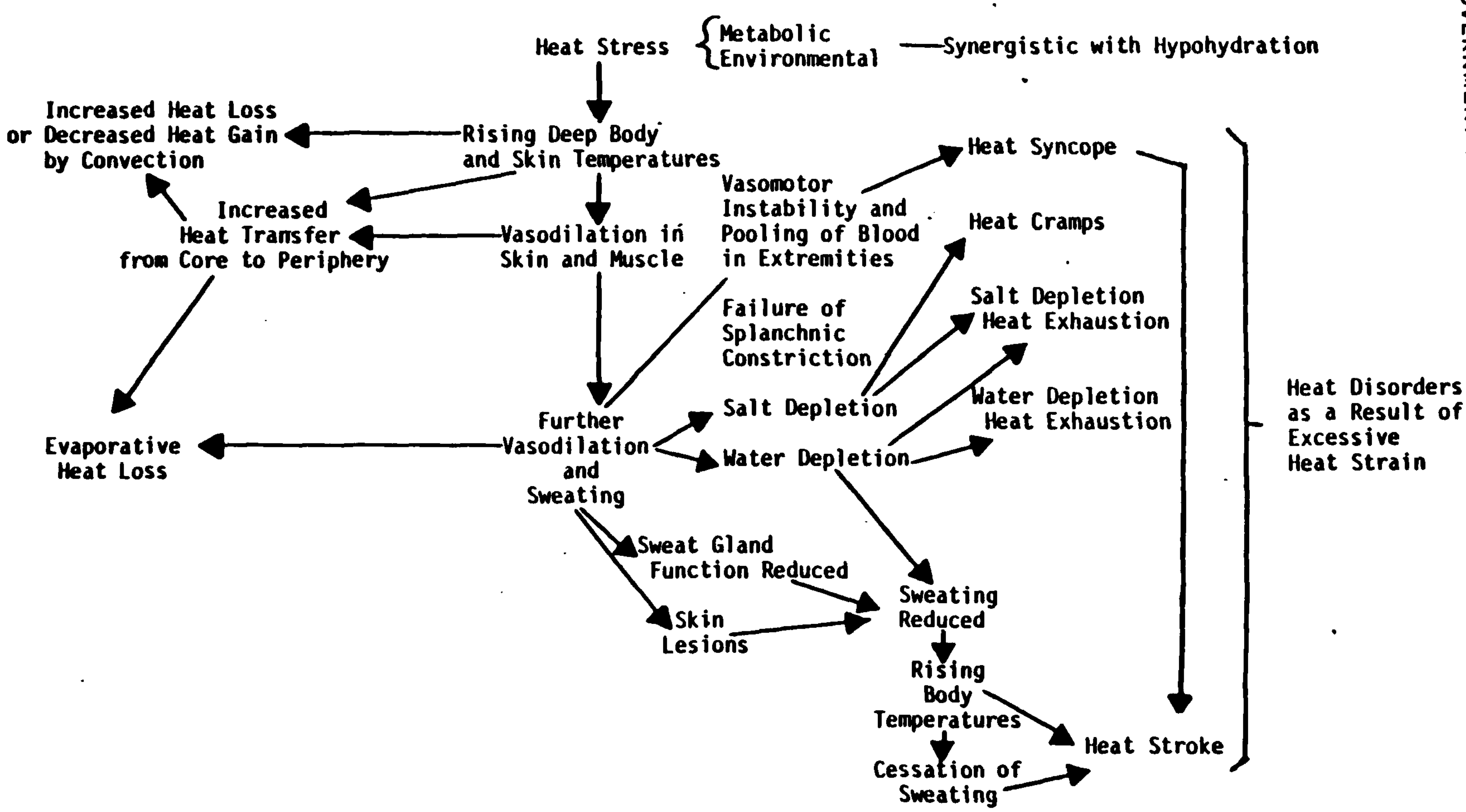
Acclimatization Of The Sweating Mechanism, Showing Progressive Increase In The Maximum Rate Of Sweating During The First Few Weeks Of Exposure To Tropical Weather (58).

evaporation and convection heat loss, while minimizing absorption of radiant energy from the sun.

Figure 17 and tables 2 and 3 summarize the entire heat stress and disorder process and further provide recommended treatment and preventive measures that should be taken.

FIGURE 17

SCHEMATIC DESIGN OF HEAT STRESS AND HEAT DISORDERS



Source: (21)

Modified from Diagram by A. R. Lind

TABLE 2

ENVIRONMENTAL AND RELATED CONSIDERATIONS IN CONDUCT OF ATHLETICS: PARTICULARLY FOOTBALL

I. General Warning
   - A. Most adverse reactions to environmental heat and humidity occur during first few days of training.
   - B. It is necessary to become thoroughly acclimatized to heat to successfully compete in hot and/or humid environments.
   - C. Occurrence of a heat injury indicates poor supervision of the athletic program.

II. Athletes who are most susceptible to heat injury
   - A. Individuals unaccustomed to work in the heat.
   - B. Overweight individuals, particularly large linemen.
   - C. Eager athlete who constantly competes at his capacity.
   - D. Ill athlete, one with an infection, fever, or gastrointestinal disturbance.
   - E. Athlete who receives an immunization injection and subsequently develops a temperature elevation.

III. Prevention of heat injury
   - A. Provide complete medical history and physical examination. Include:
     - 1. History of previous heat illnesses or fainting in the heat.
     - 2. Inquiry about sweating and peripheral vascular defects.
   - B. Evaluate general physical condition.
     - 1. Type and duration of training activities for previous month.
       - a. Extent of work in the heat
       - b. General training activities
   - C. Measure temperature and humidity on the practice or playing fields.
     - 1. Make measurements before and during training or competitive sessions.
     - 2. Adjust activity level to environmental conditions.
       - a. Decrease activity if hot or humid (see attached recommendations)
       - b. Eliminate unnecessary clothing when hot or humid.
   - D. Acclimatize athletes to heat gradually.
     - 1. *Acclimatization to heat requires* work in the heat.
       - a. Recommend type and variety of warm weather workouts for preseason training.
       - b. Provide graduated training program for first 7 to 10 days -- and other abnormally hot or humid days.
     - 2. Provide adequate rest intervals and salt and water replacement during the acclimatization period.
   - E. Replace body water and salt losses as they are lost.
     - 1. Supply cold saline - thoroughly mix one teaspoon salt in six quarts of tap water - give 3-4 oz. every 15 minutes or 8 oz. every half-hour. Flavor if desired.
     - 2. Allow additional water as desired by player.
     - 3. Provide salt on training tables and encourage salting of food.
     - 4. Weigh each day before and after training or competition.
       - a. Treat athlete who loses excessive weight each day.
       - b. Treat well conditioned athlete who continues to lose weight for several days.
   - F. Clothing and uniforms
     - 1. Provide lightweight clothing that is loose fitting at the neck, waist, and sleeves. Use shorts and T-shirt at beginning of training.
     - 2. Avoid excessive padding and taping.
     - 3. Avoid use of long stockings, long sleeves, double jerseys, and other excess clothing.
     - 4. Avoid use of rubberized clothing or sweatsuits.
     - 5. Provide clean clothing daily - all items.
   - G. Provide rest periods to dissipate accumulated body heat.
     - 1. Rest in cool, shaded area with some air movement.
     - 2. Avoid hot brick walls or hot benches.
     - 3. Loosen or remove jerseys or other garments.
     - 4. Take saline and/or water during the rest period.

Source : (21)

TABLE 3

HEAT DISORDERS: TREATMENT AND PREVENTION

Disorder	Cause	Clinical Features and Diagnosis	Treatment	Prevention
I. Heat Cramps	Hard work in heat Heavy and prolonged sweating Inadequate salt intake	Low serum sodium and chloride Muscle twitching, cramps and spasms in arms, legs and abdomen - usually after mid-day	Severe case: intravenous administration of 500 ml of normal saline Light case: oral administration of saline Rest in cool environment Salt foods used Delay 24 to 48 hours before reentering hot area	Insure acclimatization Provide extra salt at meals Drink saline when working
II. Heat Syncope	Peripheral vasodilation and pooling of blood Circulatory instability and loss of vasomotor tone Cerebral hypoxia Hyperventilation Inadequate acclimatization Infection	Weakness and fatigue Hypotension Increased venous compliance Blurred vision Pallor Syncope Elevated skin and deep body temperatures	Place supine and lower head Rest in cool environment Provide oral saline if conscious and resting Keep record of blood pressure, pulse rate and body temperature	Insure acclimatization Lighten work regimen with sudden rise in environmental temperature or humidity Avoid maintenance of upright static work conditions Comment: Predisposes to heat stroke
III. Water Depletion Heat Exhaustion	Heavy and prolonged sweating Inadequate fluid intake Polyuria or diarrhea	Reduced sweating, but excessive weight loss Elevated skin and deep body temperatures High hematocrit, serum protein and sodium Dry tongue and mouth Excessive thirst Hyporexia Weak, disconsolate, uncoordinated and mentally dull Concentrated urine	Bed rest in cool environment Replace fluids by intravenous drip if drinking is impaired. Increase fluids to 6 or 8 liters per day Sponge with cool water Provide small quantities of semi liquid food Keep record of body weight, water and salt intake, and body temperature	Provide adequate water Provide opportunity for intermittent cooling and adequate rest
IV. Salt Depletion Heat Exhaustion	Heavy and prolonged sweating Inadequate salt intake Inadequate acclimatization Vomiting or diarrhea	Headache, dizziness and fatigue Hyporexia Nausea, vomiting, diarrhea Muscle cramps Syncope High hematocrit and serum protein, but low plasma volume Uremia and hypercalemia Low sodium and chloride in sweat and urine	Bed rest in cool environment Replace fluids and salt by intravenous saline drip if drinking is impaired Provide small quantities of semi liquid food Keep record of urinary osmolarity or specific gravity, blood pressure, pulse rate, hematocrit blood urea and serum sodium or chloride Keep record of body weight, water and salt intake and body temperature	Provide adequate salt and water, 10 to 15 gms of salt per day may be necessary Provide opportunity for intermittant cooling and adequate rest Insure acclimatization Comment: Develops more slowly (3-5 days) than water depletion heat exhaustion
V. Heat Hyperpyrexia Leading to Heat Stroke	Thermoregulatory failure of sudden onset	Generalized anhidrosis and dry skin Elevated skin and deep body temperatures frequently over 40.5 C (105°F), may have chills Irrational Muscle flacidity Involuntary limb movements Seizures and coma Spotty cyanosis and ecchymosis Vomiting and diarrhea frequently with blood Tachycardia and tachypnea	Lower body temperature to 38.9 C (102°F) within 1 hour with cold rinse or spray 7.2 C (45°F). Use cool air fan or place in ice water bath. Use alcohol rinse if nothing else is available Use suction equipment to clear airway and perform tracheotomy if necessary Inject 25 to 30 mg chloropromazine every 30 minutes Bed rest in a cool environment Keep record of skin and deep body temperatures Treat secondary disorders	Insure acclimatization Adapt activities to environment Screen participants with infection or past history of heat illness
VI. Skin Lesions	Constantly wetted skin Over exposure to sun	Erythematous papulovesicular rash Itchy skin Obstruction of sweat ducts	Maintain shaded and dry skin Rest in cool environment	Dry skin when possible and keep shaded Examine skin regularly Provide opportunity for intermittant cooling and adequate sweat free periods

Source: (21)

COLD

Scientists do not agree whether or not a person can ever become fully acclimatized to cold temperatures (34). However, all agree that the most critical factor is the adequacy of protective clothing worn by the individual against the harsh environmental cold. Clothing aids in preventing the body from losing much of its internally generated heat and from gaining the cold from the external environment.

Numerous other factors influence the person's response to cold. These include the initial thermal state of the body, type and placement of the clothing, food consumed, psychological appraisals of the environmental conditions, body composition and peripheral insulation, ethnic background, sex, type and level of awareness (asleep, drowsy, or awake), ingestion of alcohol, frequency of exposure, adapttion by chronic or repeated exposure, disease and exposure to high concentration of oxygen (21).

Body fat plays a significant role in maintaining body heat in cold environments but is less effective than proper clothing insulation. In obese individuals, adipose tissue isseen as the major natural buffer against the cold. In lean individuals, maximum insulation is primarily dependent on the vasoconstriction of the skin and underlying muscle. Thus, the effective natural insulation for obese people may be as much as 4 times that of the lean, making the latter particularly susceptible to rapid cooling hypothermia unless they are adequately insulated by clothing (21). Higher heat production is required for lean subjects in colder environments while obese subjects need only a small increase in heat production.

Vasoconstriction of the skin involves the closing of the pores and tightening of the blood vessels. This prevents the human "radiator" from dissipating its interior heat to the outside, thus conserving it within. In addition, body hairs will "stand on end," naturally entrapping insulator air next to the body. Sweating will cease, as will evaporative cooling.

Effective clothing must be worn in cold environments. The clothing entraps air next to the skin and cloth weave thus increasing the thickness of the "dead air zone" and consequently decreasing the rate of heat loss by convection and conduction. The effect of clothing is illustrated in Figures 18 and 19. Figure 18 depicts the minimum amount of clothing required of pilots as a function of temperature and time; Figure 19 illustrates the typical clothing required as a function of temperature and level of physical activity.

Normal daily clothing can decrease the rate of heat loss by about half of that lost by the nude body. Heavy winter clothing is considerably more effective, however, it can be a disadvantage in that it tends to restrict movement

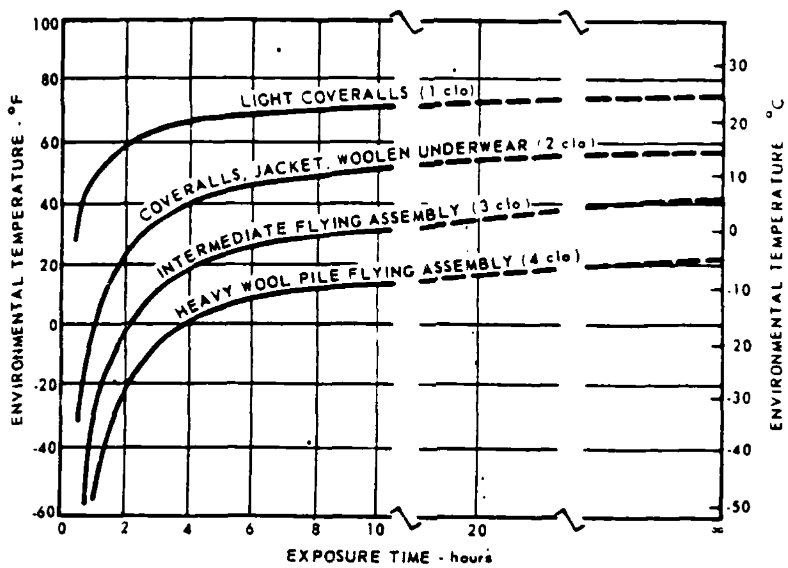


FIGURE 18

Minimum Amount Of Clothing Required Of Pilots As A Function Of Temperature And Exposure Time. Adapted from (150).

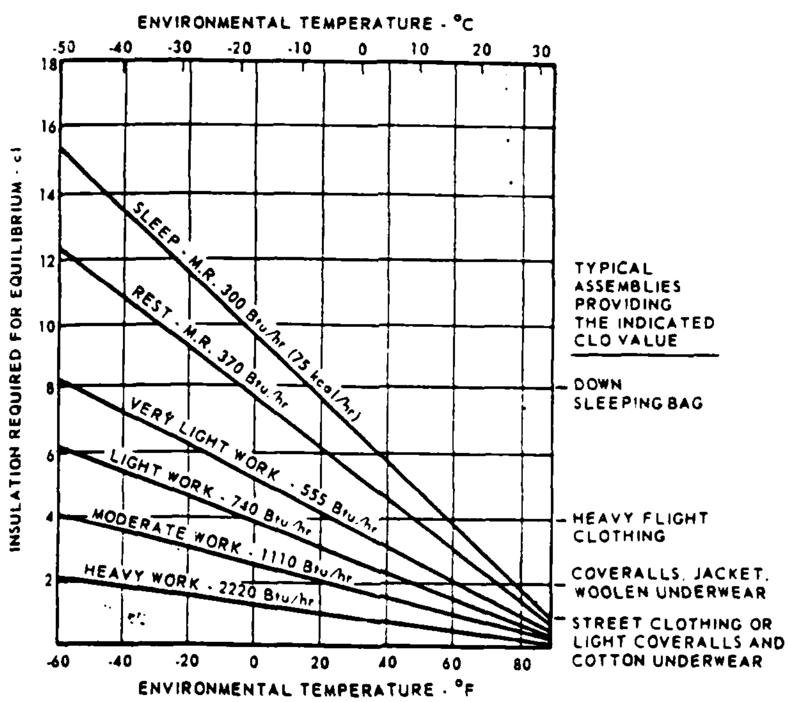


FIGURE 19

Typical Clothing And Insulation Required As A Function Of Temperature And Degree Of Physical Activity (150).

and dexterity;for example, thick gloves make hand manipulation quite difficult and reduce productivity. Also, the shedding or donning of clothing when entering or leaving a cold environment is time consuming.

Wet clothing is ineffective in the prevention of heat loss due to the lack of entrapped air when the water and clothing material cling to the skin. Making matters worse, because of the high conductivity of water, it actually increases (5 to 20 times) the rate of heat transmission from the body to the environment (58). Not only is it important that the clothing does not get wet from the exterior environmental factors, but sweating in overly hot clothing prior to exposure to the the cold can be equally detrimental.

Once one's body temperature falls below 94°F the ability of the hypothalamus to generate heat is impaired and completely ceases at 85°F. Temperature regulation stops as the bodily cells become adversely affected by the cold. Sleepiness and coma most probably develop, which in turn, minimize the central nervous system's ability to generate more additional heat. Heart failure and death can be expected at a body temperature of 75°F (25°C).

Frostbite occurs when exposed body parts actually freeze due to extremely low temperatures. Ice crystals form in the tissues with subsequent ulcers which are slow to heal. It is most likely to occur first at the earlobes, followed by the fingers and toes.

Prolonged freezing results in permanent circulatory impairment as well as permanent damage to the tissue, resulting in gangrene and ultimate loss. The frozen body part may be saved only if immediately thawed in water at a temperature less than 110^{o}F. Frostbite is possible under less than severe conditions as evidenced by the US Forces during the Korean War where frostbite resulted from 5-35^{o}F air with winds at 1-4 mph and relatively low humidity. In the majority of cases, the soldiers suffered from 7-12 hours of exposure with wet hands and/or footware (50).

As shown in figure 20, performance is detrimentally affected by cold environmental temperatures. For manual tasks, the effect of hand-skin temperature is critical to capability, dexterity, strength, numbness, and reaction time. Severe cold exposure effects manual performance, reduces skin surface sensation, affects muscular control, and reduces the mobility of the joints. Figure 21 shows how efficiency is effected in various tasks at various temperatures. McCormick (98) relates that in a test where 22 men lived in a room for 8-14 days at a temperature of -20^{o}F, they experienced deteriorating manual performance, but mental and visual performance remained unaffected.

In other experiments, knot tying performance was affected when hand-skin temperature was lowered to 55^{o}F (22) (87). Performance on a task involving rotation of an object between the thumb and forefinger was impaired at a

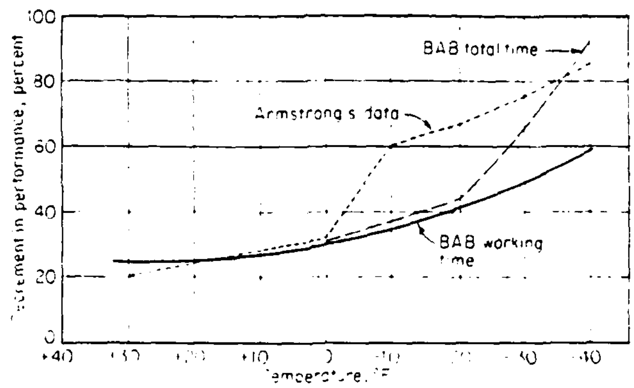


FIGURE 20

Percentage In Decrement In Performance On Two Tasks Under Different Temperature Conditions. Brush assembly breakdown (BAB) is a type of industrial line maintenance job whose total time includes warmup time. Armstron's data relates to operational efficiency of flying personnel in open cockpits (98).

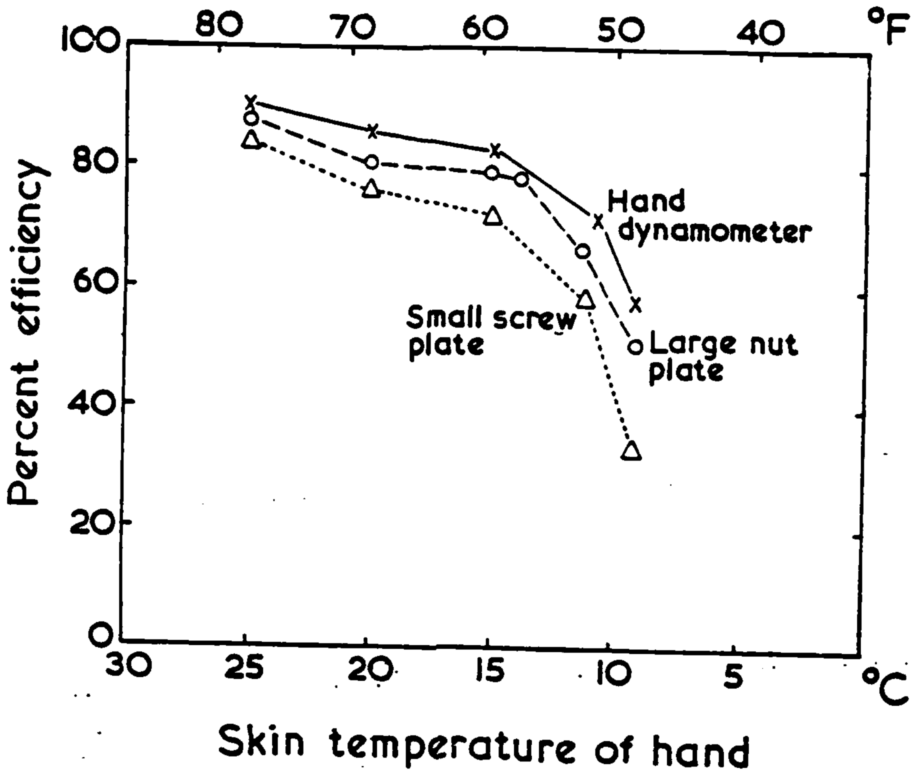


FIGURE 21

The Average Deterioration In Various Manual Tasks Produced By A Fall In The Temperature Of The Hand. Efficiency is expressed as a percentage of the efficiency in ideal conditions. The unbroken line shows the diminished strength of handgrip measured with a hand ergometer. The broken line shows the reduced number of .6 inch hexagonal nuts threaded onto screws in a fixed time. The dotted line shows the reduced number of .2 inch screws screwed into a metal plate. The results are from six people (77)(124).

skin temperature of 68°F,and hand and grip strength was gradually reduced as the forearm muscle temperature was reduced to 86°F (64) (87). Stang and Wiener (138) found in an experiment that, under cold water, divers were able to perform at 50°F for 90 minutes, but a large decrement in performance was experienced. Grosser movements were less effected than were finer movements.

The variable factors affecting the performance are the location of cold exposure, the level of exposure, the rate of cooling, and the type of manual performance involved.

The application of auxillary heat to the hands can eliminate or prevent performance decrement as told by Lockhart and Kiess (64) (87) even though the hand-skin temperature remains below the critical 55°F temperature.

PRODUCTIVITY

Through various observations and laboratory tests, the point of maximum productivity occurs at about 75°F and 60% humidity. Figure 22 is an isopleth which relates, in this case, mason productivity to temperature and relative humidity. The numbers within the oblong areas indicate percentage of productivity when "normalized" by equating the highest productivity rate (55%) and equating it to "1.00". The rectangular area is considered by ASHRAE to be the "comfort zone". (54) (124).

Of course, the "ideal" environmental effective temperature depends upon the culture, the person, and the task. Some workers involved in extremely rigorous tasks prefer to work in 50°F temperatures. Acclimatization appears to be a factor as noted from the fact that the British generally prefer cooler conditions than the Americans.

Few, if any, people, however, enjoy working under the extreme conditions identified herein.

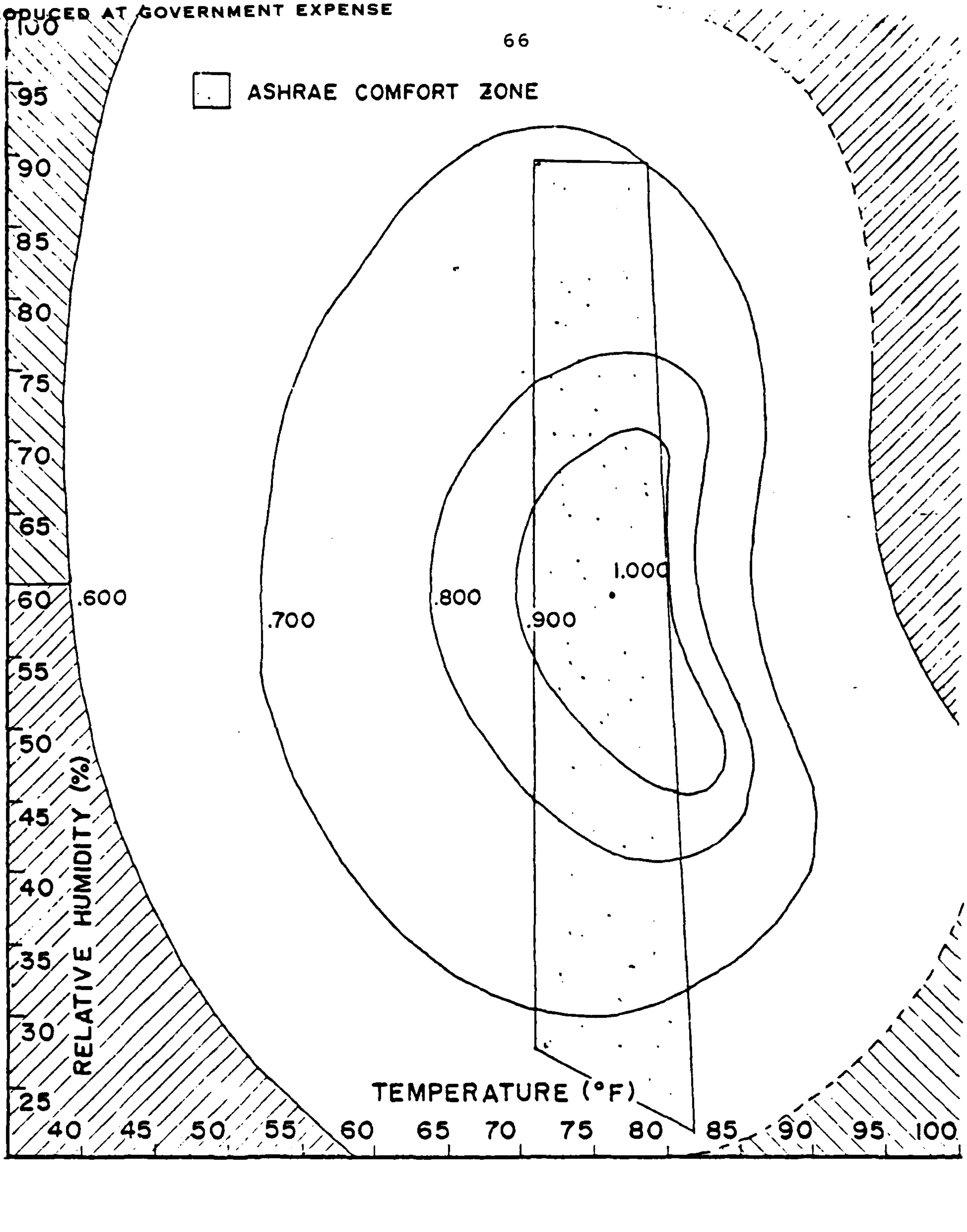


FIGURE 22 Normalized Productivity Isopleths

Source: (54)

RECOMMENDATIONS

HEAT

(1) Lower the average hourly expenditure of energy either by REDUCING THE RATE OF WORK or by keeping the rate of work constant but introducing PERIODIC REST PERIODS under cool conditions.

(2) Although acclimatization can be achieved within 4-7 days, if there is a considerable workload, it is best to INTRODUCE THE WORKLOAD IN 2 STAGES. NIOSH recommends that the worker should begin with a 50% exposure to work in the heat on the first day, to be increased by 10% daily.

(3) Be aware that although acclimatization may last from two weeks to several months, some is lost over periods as short as a weekend, and a two week lack of exposure may again require a 4-7 day reacclimatization. JOB ASSIGNMENTS SHOULD BE PLANNED ACCORDINGLY.

(4) Because of the serious consequences of dehydration, ENSURE THAT COOL WATER IS MADE AVAILABLE to the workers and ENCOURAGE THEM TO DRINK FREQUENTLY. In addition, SALT TABLETS SHOULD BE MADE AVAILABLE, as acclimatization will not occur if salt intake is less than 5-6 grams per day.

(5) Workers going to known hot climates should undergo thorough PHYSICAL EXAMINATIONS. Illnesses adversely affect a person's ability to acclimatize, particularly if dehydration is a normal symptom of those illnesses.

(6) CAUTION WELL-MOTIVATED WORKERS who tend to overlook the warning signs of over exertion in heat, as this enthusiastic effort may cause them to literally work themselves to death by heat stroke.

(7) ENCOURAGE GOOD PHYSICAL CONDITIONING in the workers. The likelihood of heat stroke is 3½ times more likely in workers 40 lbs overweight than in workers 10 lbs overweight (109).

(8) USE SCHEDULING TECHNIQUES that will counteract the effects of weather: perform exterior work in spring and fall, perform interior work during the winter, and work in shade or in breezy areas during the hot periods, and start summer work days in the early morning hours to avoid the hot afternoon sun.

(9) Performance may sometimes be maintained in a hot climate at normal levels IF A WORKING INCENTIVE FOR THE TASK CAN BE INCREASED (118) (119). Being mindful of heat stress and stroke, the reader is cautioned that this is best for sedentary or not highly physical exertion tasks.

(10) If management desires to maintain production while the workers slow down on a hot day, use of TEMPORARY WORKERS should be considered to augment the workforce.

(11) INFORM THE WORKERS about the proper drinking and salt supplementation practices, as well as how to recognize the symptoms of heat disorders and illnesses.

(12) In some cases where workers are not required

to remain on the job for the entire shift if they complete their work early, they tend to rush in order to leave earlier, increasing their vulnerability for heat exhaustion or stroke. As a result, THE TOTAL WORK SHOULD BE DISTRIBUTED EVENLY OVER THE ENTIRE SHIFT, except that the most strenuous work should be performed early in the day when the temperature is still relatively cool.

(13) POST WARNING SIGNS around jobsites where the environmental heat exceeds 86°F (T_{WB}). Do not allow work within the zone out of eyesight of fellow workers. Such spaces may include attic areas, crawl spaces, steam tunnels, storage tanks, etc.

(14) SET STANDARDS FOR CLOTHING best suited to protect the worker from hazardous environmental temperatures.

COLD

(1) PROVIDE ENCLOSURES OR WINDBREAKS for workers exposed to temperatures below 40°F and to winds in excess of 15 mph.

(2) ENSURE THAT WORKERS ARE AWARE OF THE EFFECTS OF SEVERE WORKING CONDITIONS and the types of clothing best suited to provide the needed protection.

(3) PRECLUDE WORKERS FROM HAVING TO WORK IN WET CLOTHING which is detrimental rather than beneficial in maintaining effective body heat.

(4) PREVENT WORKERS FROM HAVING TO WORK IN OVERLY WARM CLOTHING prior to working in the cold, as this will have the

same effect as working in wet clothing.

(5) KEEP THE WORKERS ACTIVE IN PHYSICAL ACTIVITY both to help generate body heat and to psychologically take their minds from the extremely harsh conditions.

(6) Provide a location or means of AUXILIARY HEAT to warm body parts most susceptible to frostbite and performance degradation.

In summary, in both hot and cold, it is of utmost importance that both management and the workers seriously consider the overall effects of the extreme conditions, take decisive preventive measures to prevent injury or death, and to seriously consider possible alternate solutions to maintaining human productivity and efficiency without degradation of human safety.

5. THE DAY-NIGHT SLEEP CYCLE

(SHIFTWORK)

GENERAL

The adoption of an 8 hour day and a 48 hour week was largely a post-WW I development, having been incorporated at the first convention of the International Labor Conference of 1919. The demand of the workers' movement for an 8 hour day was based on the idea that out of a 24 hour day, an individual should dedicate 8 hours to work, 8 hours to recreation, and 8 hours to sleep. The three-shift operation, although not previously unheard of, is a product of the last 65 years.

Shiftwork is considered necessary for several reasons. Socially, it provides for round the clock services as in the cases of hospitals, fire departments, police departments, power plant and transportation systems. Technologically, it provides for uninterrupted processes precluding product deterioration or destruction, as in steel or chemical production. Economically, it provides for the most efficient use of facilities and equipment and allows for planned preparation for the next day's activities.

Although not used as extensively as in other industries and services, shiftwork is used within the construction industry for each of the reasons cited above. For example, evening and night shifts may be required to perform highway work when traffic volume is low compared to the daytime volum when a conflict between the traffic and work effort would otherwise result. Technologically, shiftwork may be required to assure an uninterrupted concrete pour or to take advantage of tides and currents. Economically, it may preclude the need for idle construction equipment or be a boom to scheduling by allowing the excavation of a trench ahead of pipe emplacement, or the installation of rebars and forms prior to pouring retaining walls.

Functionally and materially, shiftwork appears to be an industrial blessing, as it makes the most effective use of time. Often overlooked, however, is the effect that shiftwork has on the workers who are expected to perform to the same levels and standards during the night hours as their daytime counterparts.

Management must be aware of the actual benefits and detriments of shiftwork as they relate to human performance and the wellbeing of the worker. With proper planning and scheduling, production volume, employee motivation and morale, safety performance, job completion time, quality of workmanship, and, of course, costs and profits will turn out for the better.

PERFORMANCE

The effects of shiftwork on individuals are not universal. Individual differences involving attitudes, patterns of living, and likes and dislikes result in differences in tastes and opinions about specific hours of work, duration of work shifts, preferred duties within the shifts and patterns of living outside of the shift hours. Keeping that in mind, the possible effects of shiftwork are many and of varying degrees.

Before discussing these possible effects, it is necessary to identify the "Circadian Cycle" or "Circadian Rhythm" which mutually affects and is affected by shiftwork to a great extent. The term is derived from Latin meaning "approximately one day" and is associated with the day/night cycle. It is the rhythm of man's internal physiological clock, determining sleep and wakefulness, and is a direct result of the rotating earth (64) (87).

Circadian rhythms are thought to be synchronized with the 24 hour period by periodic factors, or cues, in the environment that are known as "zeitgebers" (from German meaning "time givers") such as the 24 hour light/dark cycle, knowledge of clock time, changes in environmental temperatures, and the everyday patterns of society (43).

For the majority of animals, the light-dark cycle is the most powerful zeitgeber. For humans, however, social cues and awareness of clock time are of prime importance (130) (4). Aschoff (4) describes an experiment where 12 subjects lived on a strict schedule of sleep and wakefulness. During the first 4 days conditions were such that the subjects were exposed to alternating light and dark while during the second 4 days they were exposed to total darkness. Their circadian rhythms during both situations were identical. If the light/dark cycle were as powerful a zeitgeber for humans as it is for animals, some significant change to the cycle would have been expected. As a result, Aschoff concluded that light is a relatively unimportant influence on man's circadian rhythm and that social cues appear more significant.

Nevertheless, light is still a most powerful zeitgeber for man and many investigators cite specific problems which arise when the sleep-wake cycle becomes out of phase with the light-dark cycle.

Within the body are various other physiologic rhythms including temperature, sleep, excretory and heart rate. (See figure 23). When the zeitgeber is shifted, these physiologic rhythms either shift with it or become desynchronized, not only with it, but with each other. As a result, the temperature rhythm, when out of phase with the light-dark cycle, may run according to a different schedule than the heart rate rhythm does.

Luckily, these cycles will not remain out of synchronization indefinitely and within a short time (to be discussed further) self-adjustments will be made to get back into phase with each other and to the new schedule. For that reason, changes in zeitgebers do not appear to adversely affect workers who are assigned to a specific shift on a permanent basis.

In the case of rotational shift workers, however, each internal cycle must adapt each time that the schedule changes, and usually, just as the readjustment is being made, the schedule is changed again. The repeated changes can be harmful, both physically and mentally to the worker.

As of 1979 there appear to be only six known published studies showing how 24 hour real-life performance is related to shiftwork (21) and none are associated with the construction industry. However, all six agree that there is generally a major impairment during the nightshift whether it involves speed, accuracy, or accidents. Figure 24 illustrates these job performance variations over time for each of the six evaluations.

Wojtczak-Jaroszowa and associates (156) reported similar results in 1978 when they found that, all things being equal, performance levels among glass cutters is lower during the nightshift than during both the morning and afternoon shifts. They further found that performance deteriorated as the shift progressed and that physical exercise had a considerably favorable impact. With regards to the latter, when testing was preceded by light physical exercise, performance actually improved, probably as a result of raising individual arousal. Conversely, the authors found that hea y work has an opposite effect, suggesting that there is an "optimal level of arousal".

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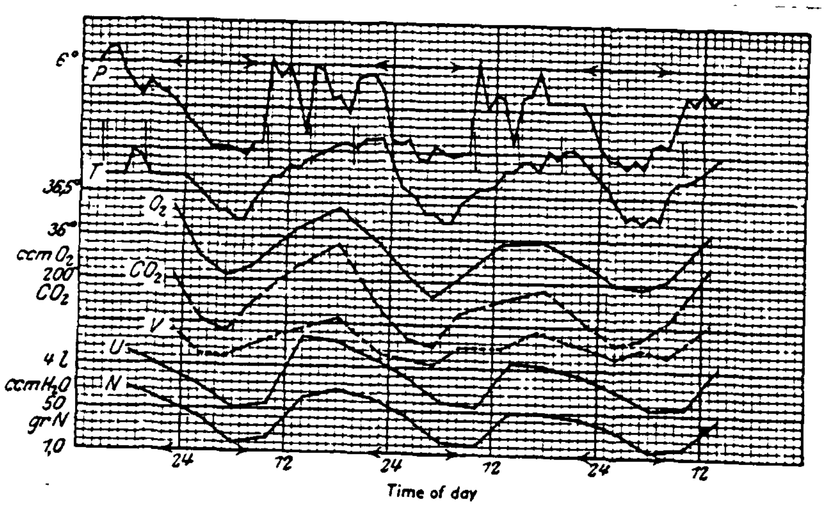

FIGURE 23

The Course Of Some Diurnal Functions In Man. Double arrows represent the period of sleep in the subject; vertical lines, mealtimes; P, pulse rate; T, temperature; O_2, oxygen consumption; CO_2, CO_2 production; V, ventilation; U, urine excretion; N, nitrogen content of urine (20).

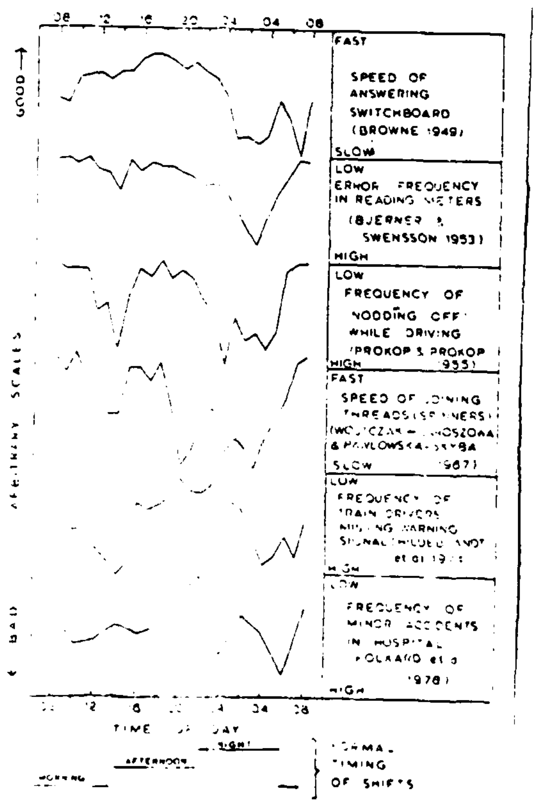

FIGURE 24

Variations In Job Performance Over The 24 Hour Period (10) (17)(42)(43)(66)(125)(157).

In further experimentation, Tasto (141) found that rotating shiftworkers experienced more physical maladies than did dayworkers. The shiftworkers became sick more frequently, used jobsite health clinics more often and were prone to more accidents. In surveys and dispensary monitoring shiftworkers were found to experience more ingestion, leg and foot cramps, colds, chest pains, menstrual problems, nervousness/shakiness, alcohol consumption and fatigue.

One of the greatest problems with shiftwork is its effect on sleep disturbance. Many workers have difficulty sleeping during the day and getting their needed quotas of sleep. These might include noise from children or traffic, the need to keep daytime appointments or to participate in social activities with family and friends. A person who has lost five or more hours of sleep is likely to be less efficient than normal, even if it had been lost over a period of successive days. Recovery after a full sleepless night takes longer than 24 hours. After 4 or more days without sleep, a person will have short lapses of being "out of touch" with the surroundings, may not be able to distinguish between real and fantasy, and there may be changes in personality (124).

People do not sleep deeply all night. Poulton (124) describes the sleep pattern in this way:

> They start by descending rapidly into the deepest sleep, and after 1 hour begin sleep-

> ing lightly for some 15 minutes before sleeping deeply again. Cycles of deeper followed by lighter sleep last on the average some 70-90 minutes, with the length of time in each deep sleep session decreasing as the night passes.

In figure 25 the electroencephalographic (EEG) recordings, show brainwaves of individuals in each stage of sleep or wakefulness. Alpha waves occur during a state of wakefulness. With the onset of light sleep, the rhythm changes into slower, larger waves. During medium sleep, spindles (short bursts) appear. Dreams appear during light and medium sleep after the deep sleep period, where electric waves show a higher frequency. A nightmare can cause bursts of more frequent and violent oscillations. Delta waves which show decreased frequency, are indicative of deep sleep (139).

Sleep taken during the day shows the reverse of that taken during the normal nightly hours. As the daylight passes, the sleep proceeds from a very light sleep to a much deeper sleep. Thus, if the sleeping time is cut short for any reason, the individual is deprived of the proper quantity of deep sleep that is required.

Maurice and Monteil (97) (130) have shown that 50% of the population is accustomed to sleeping 7 to 8 hours on normal working days. When the evening shift ("swing shift") is worked this percentage drops to 40%. When the nightshift ("graveyard shift") is worked the percentage drops to about 35%. Furthermore, it has been noted that this percentage

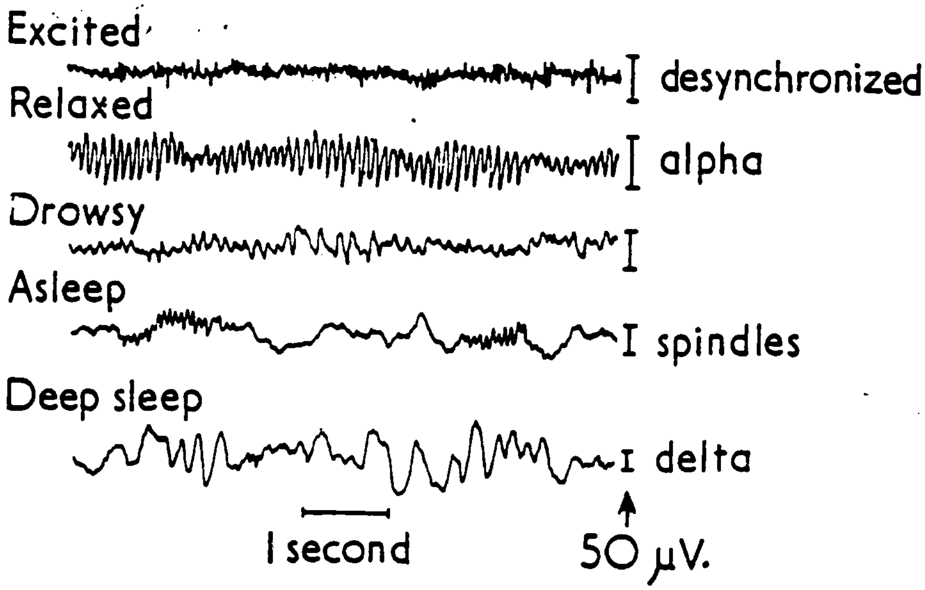

FIGURE 25

Characteristic Records Of A Person's Brain Waves Made By An Electroencephalogram (EEG). They have been arranged in order of brain activity from the very active at the top to deep sleep at the bottom. The vertical bar to the right of each record indicates the amplitude which represents 50 microvolts. The horizontal bar at the bottom represents the duration of one second (117)(124).

drops to about 15% on the day after completing a series of work days on the night shift.

Individuals differ greatly in their ability to adapt to the radical changes required of them in modifying the sleep-wake cycle. Some adapt very easily and readily, accepting the inversion both physiologically and psychologically. Others adapt very slowly or not at all. Generally "morning people" (those who are alert and active early in the day) have been shown to display the greatest difficulty in adapting to the shift system, and that "night people" (those who function best during the dark hours) have least difficulty in adapting to the rotational shift system. Also, of the three usual shift periods, the night shift (midnight to 8 A.M.) usually causes the most difficulties, and as it affects sleep, the evening shift (4 P.M. to midnight) has the least impact because a worker can get a full night's sleep by getting home soon after midnight and "sleeping in" late in the morning (135).

Of all the various bodily cycles, performance is most clearly correlated with the temperature rhythm. Colquhoun and associates (29) in studying both rotating and permanent shiftworkers found that body temperature is a predictor of performance efficiency. Performance is optimal when body temperature is high and minimal when the body temperature is low.

Figure 26 shows a hypothetical example of a perfect body temperature phase shift. Here the normal oral temperature circadian rhythm (solid line) is shown. If complete adjustment occurred as a result of a change in a shiftworker's sleep-wake cycle, the whole rhythm would be phase shifted to the position shown by the dotted line. Investigators have shown that such phasing occurs only after a considerable number of days on the phased shift (43).

Figure 27 illustrates how well the body temperature rhythm adjusted to a new shift cycle after a ten day period of individuals working on the night shift. Additionally, the performance on various tasks is also shown. Perfect adjustment would be represented by a value of 100. As can be seen, mental tasks adjusted more easily than did perceptual (visual search) and manual (dexterity) tasks (43).

Tilley and associates (143) in other experimentation involving rotational shift workers, found that the rotation time of those on night shifts was impaired and deteriorated as a function of the number of days into the shift and the time on the task. The authors theorized that this deterioration over time is a result of accumulated sleep deficit.

Tasks which are monotonous or that require little activity are particularly susceptible to the effects of sleep loss due to the worker's lower level of arousal. Memory is adversely affected by sleep loss as is the ability to maintain a train of thought. Additionally, workers become irritable and argumentive as a result of sleep loss.

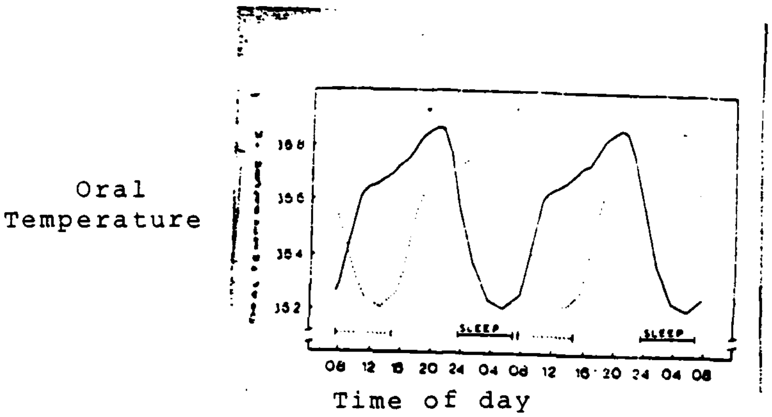

FIGURE 26

The Normal Circadian Rhythm In Body Temperature (solid line) And A Representation Of This Rhythm (dotted line) When Perfectly Adjusted To An 8 Hour Change In Living Routine (28)(43).

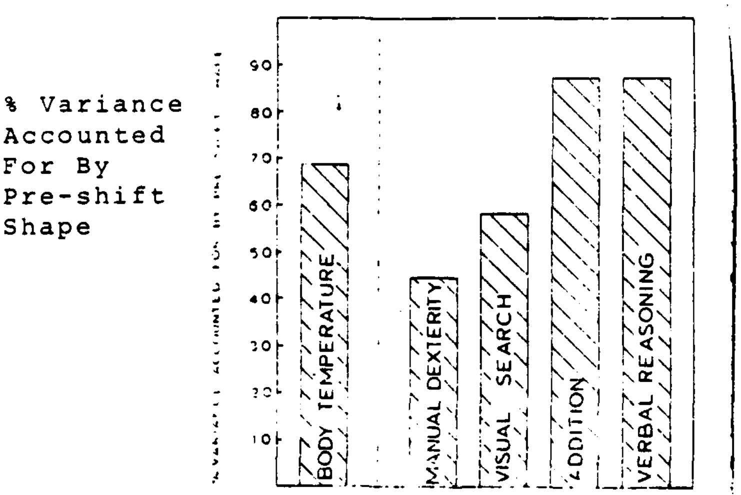

FIGURE 27

The Degree Of Adjustment Of The Rhythm In Different Performance Measures (and urine flow temperature) On The Ninth And Tenth Days Of Nightwork (43).

Assignment to a shift system not only affects a worker's sleep-wake pattern but also affects morale and motivation by possibly interfering with the social life and participation in activities which take place while at work or when sleeping; by interfering with the obligatons to the family, particularly as spouse or parents, in being precluded from being available with loved ones at mutual times; by forcing workers to participate in situations they are not fond of (only about 30% of workers like shiftwork) or have difficulty adjusting to; or by causing other physiologic problems related to poorer eating habits (as indicated by the greater number of digestive disorders experienced by shiftworkers because of irregular meals and unbalanced diets) or physical exercise.

In addition, certain other health disorders which in themselves follow a circadian rhythm can be worsened when individuals are subjected to rotational shift adjustments at a rapid rate. These include diabetes which requires timed insulin/glucose dosages; asthma, tuberculosis and heart disease which often show patterned traits; and epilepsy where seizures generally follow a timed pattern of occurrence either during the day or night.

One's circadian rhythm will not be significantly disturbed by a single night shift. However, as a result of the time required for one's circadian and bodily functions rhythms to adjust to the new sleep-wake cycle mandated by a shiftwork assignment, it is generally believed that managers are committing a gross error in scheduling rapidly changing, rotational shifts, particularly in performing manual tasks as are most likely required in the building trades. Instead, an individual's working efficiency can best be maintained by either switching to a permanent shift basis or rotating no more frequently than once every 3 to 4 weeks. Figure 28 shows a definite advantage of working on a night shift for as little as two weeks when compared to doing so for just one week.

To be a top performer, a person needs to be both awake and accustomed to working at night. Poulton (124) states the ideal three-shift system for working a year involves each worker working at night for a continuing 4 months. However, because of the dangers of accumulated sleep loss, during weekends and other times off from work, the worker must take care not to revert to sleeping at night and staying awake during the day.

The level of performance on shiftwork, particularly on the night shift, depends on primarily three factors: (1) the demands of the task (Is it monotonous or stimulating? Manual or perceptual?), (2) the type of shift system (What is the shift cycle? How much of an adjustment period is there?), and (3) the workers' abilities to adjust their

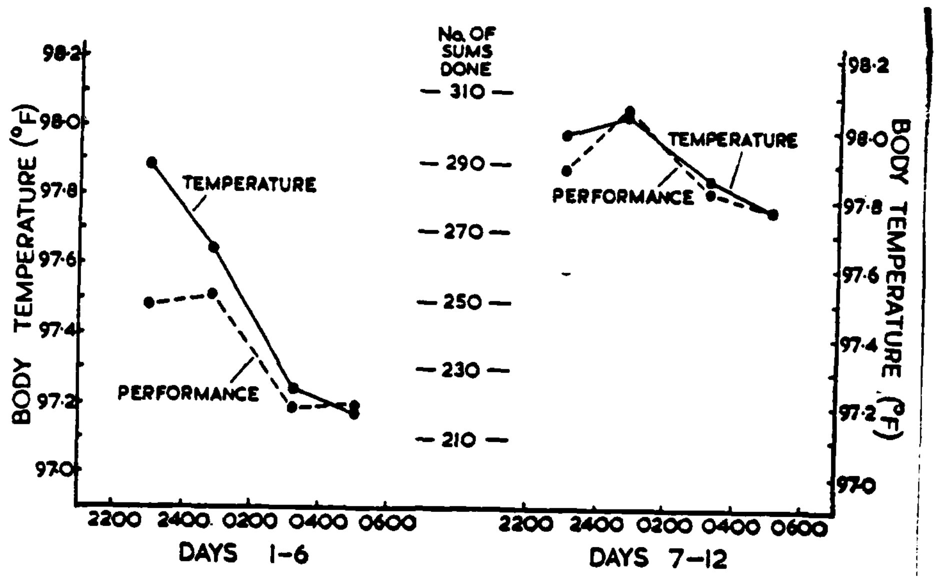

FIGURE 28

The Average Body Temperature And Rate Of Work Of A Group Of 10 Young Enlisted Men During The First And Second Weeks Of Night Duty. Results of the first week are given on the left. The unbroken line shows the average fall in body temperature during the 8 hour work shift. The broken line shows the corresponding fall in the average number of simple addition sums completed in 48 minutes...The results for the second week are given on the right. There was a smaller average fall in body temperature during the second week of the shift. There was a correspondingly smaller fall in the average rate of work. Also, performance had increased in speed in the second week as a result of practice (29)(124).

rhythms to night work (Can their sleep patterns be adjusted? What is the home and social environment like?)

Not only is the circadian rhythm affected by shiftwork, but other practices may also have an influence. One of these practices is that of overtime. Workers are frequently required to work overtime in order to accomplish certain tasks. This added work could have an adverse impact on the body cycles of workers.

Lengthened work days are frequently used in the construction trades. Worker productivity depends on the length of each overtime period and the frequency with which the periods are scheduled. Workers who are assigned 4 hours of overtime after working an 8 hour shift may be 100% effective during the entire period. However, if the same hours of overtime were repeated consistently over several days or weeks, productivity could be expected to show a substantial decrease. (See figure 29.) McNally and Havers (106) report that a workweek of 6 ten-hour days will yield about the maximum total performance. This of course, does not provide the optimal production per unit time. In addition, they indicate that when doing non-repetitive tasks, the second shift will normally have 93% of the first shift's productivity and the third shift about 88%. The exception occurs at extremely hot climates where performance may improve during the cooler night hours.

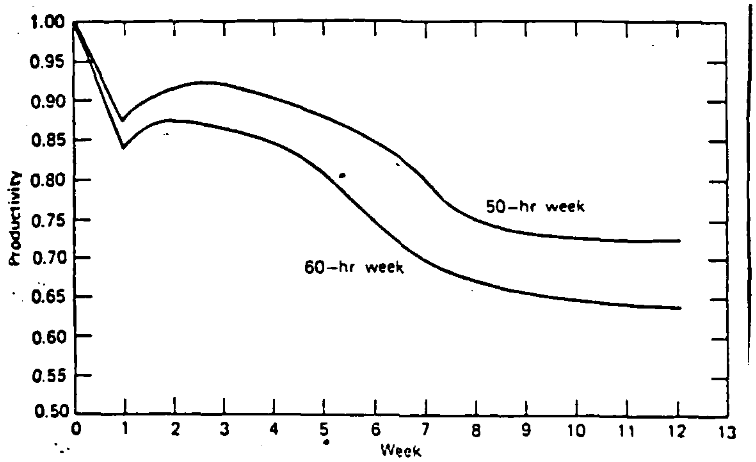

FIGURE 29

The Cumulative Effect Of Overtime On Productivity For 50 And 60 Hour Work Weeks (63).

RECOMMENDATIONS

Considering all of the presented factors which have a bearing on performance and productivity, the following recommendations are made:

(1) Shiftworkers should be in relatively GOOD PHYSICAL CONDITION and should not suffer from illnesses or require medication which would be disrupted by rotating shifts.

(2) Workers subject to DEPRESSION AND EMOTIONAL PROBLEMS SHOULD CAREFULLY BE CONSIDERED before being assigned to shiftwork. Shiftwork assignments may place too great a stress on workers who might otherwise be able to cope with their emotional problems.

(3) Management should SCHEDULE SHIFTS SO THAT THE WORKERS HAVE AMPLE TIME FOR THEIR PSYSIOLOGIC RHYTHMS TO ADAPT to one schedule before having to adapt again to another. Thus, a worker should spend at least 3 to 4 weeks on the same shift before being required to change again.

(4) Management should ensure that shiftworkers REALIZE THAT ACCUMULATION OF SLEEP DEFICIT OVER SEVERAL DAYS MAY BE A HEALTH RISK FACTOR and consequently should be avoided.

(5) AVOID REPETITIVE, MONOTONOUS WORK during the late shifts, whenever possible.

(6) ADEQUATE INCENTIVES psychologically motivate workers to accept the undesired shiftwork more readily, affecting morale and ultimate output.

(7) Provide for REGULARLY SCHEDULED EATING PERIODS, and if possible, availability of hot meals if desired by workers, in order to ensure the opportunity of having regular, balanced meals.

Productivity is a direct result of worker efficiency and the worker's ability to perform the task. Unless the worker is both physically and mentally prepared to take on the task, productivity will suffer. Although managers cannot dictate workers' daily lives and practices, they can take precautions to select personnel, tasks, and schedules most adaptable to performing the required work in the best and most efficient manner possible.

6. NOISE

GENERAL

As early as 1884 it was observed that loud music caused convulsions with epileptic patients due to the effect that noise has on the central nervous system (2). It was the advent of steam power during the Industrial Revolution that first brought general attention to noise as an occupational hazard (65). Until the early 50's it was believed that continuous noise had no effect on human performance. However, since that time there have been indications that noise can adversely affect performance of workers when performing certain tasks particularly susceptible to distraction (14) (74) (124).

What is "noise"? Andreyeva-Galanina and associates (2) define noise as "a complex of sounds, unfavorably affecting the human organism, disturbing his work and rest." Hersh (65) describes it a bit more directly:"Noise is any undesired or harmful sound." And McCormick (98) defines it as "that unwanted sound which has no informational relationship to the task or activity at hand."

"Sound" is defined as "acoustic energy between 2 and 20,000 hertz (hz), the typical frequency limits of the ear" (81). A hertz is a unit of frequency equal to one cycle per second (cps). The ear is 10 million times more sensitive to high tones than to low ones. Sound is produced by the vibra

AD-A163 712 THE EFFECTS OF ENVIRONMENTAL FACTORS ON WORKER PRODUCTIVITY IN THE CONSTRUCTION INDUSTRY(U) WASHINGTON UNIV SEATTLE E F ST. GERMAIN JUL 85 2/2

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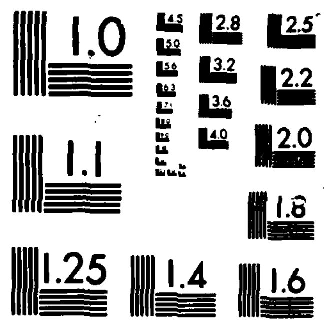


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

tion of bodies or air molecules and is transmitted by longitudinal wave motion.

"Loudness" is the perceived magnitude of sound and is a function of both intensity and frequency (159). Sound wave frequencies are normally grouped as follows:

low frequency	300-400hz	(quiet running, non percussive machinery or sound heard through sound proofing)
middle frequency	400-1000hz	(internal combustion engines, machine tools)
high frequency	1000hz &up	(ringing, hissing, whistling, percussive units)

The"decibel" (db) is the common unit for measuring sound intensity and represents the rate at which a sound passes through a unit area perpendicular to the direction of sound. Because of the extreme changes in sound intensities that the inner ear detects and sends by nerve pulses along nerve fibers to the brain centers, sound intensities are usually expressed in terms of the logarithm of their actual intensities. One decibel represents an actual increase in intensity of 1.26 times (98). Because of its logarithmic character, a noise level increase of 10db is 10 times (1.26 to the 10^{th} power) greater while a 20db increase is 100 times (1.26 to the 20^{th} power) greater.

The behavioral effects of noise are as complex and ill-defined as noise itself. To this day researchers disagree over which noises are actually harmful and which, if any, may actually be beneficial to performance. Noise interferes with communication, rest, and attentiveness. Safety is affected by all three. All researchers are certain, however, that at specific levels of loudness over time, severe damage can be sustained by the ear, and to various other components of the human body as well.

Despite the numerous unknowns still associated with noise, it is certain that there are harmful effects...effects with which management should be concerned and against which preventive measures should be taken.

EFFECTS

Noise, by itself, probably does not bring about a degradation in human performance. However, when it is coupled with other variables such as duration, worker sensitivity, direction, task boredom and start (startle effect), adverse effects on performance are probable, particularly on complex mental tasks involving skill and speed, high perceptual capacity, or constant attention to detail.

Laboratory work has shown that:

> Any person exposed to a high noise level to which he is not accustomed will at first only suffer a mild discomfort, but after a time, he will be subjected to changes in mood. Emotional responses may become more extreme and it is not uncommon to 'fly off the handle' at the slightest provocation (129).

Fatigue and lethargy are also common in noisy environments.

Construction sites have numerous sources of noise. Heavy equipment such as bulldozers, backhoes, compressors, generators, concrete mixers and dump trucks maintain constant levels of irritating and damaging noise. Blasting, pile driving and jack hammering warrant particular concern because of the considerably high noise levels reached and the type of physiological damage their output, impulse noise, may have on the human body.

Throughout American industry, including the construction industry, noise-induced hearing loss is a major health problem. Noise surveys have identified a multitude of machines which generate harmful noise levels. Rotating and reciprocating machines generate periodic sound while air moving equipment generates broadband random sounds. The highest noise levels are caused by components of gas flow systems that move at high speeds (steam pressure relief valves, fans) or by impacting operations (riveting, jackhammering, road breaking) (159). Estimates that the number of US workers exposed to hazardous noise conditions are in excess of 6 million and may be as high as 16 million (27) (47).

Table 4 is based on 8 hours of daily exposure and shows the sound intensitites at which there is cautionary or serious risk resulting in the effect shown in column 1. For example, 70 db represents a cautionary risk of hearing damage; exposure between 70 db and 90 db entails some risk; and exposure over 90 db represents a serious risk (65). High frequency normally produces more injury than lower frequency, while intensity and duration are given equal weight.

The loudest noise that the human ear can tolerate is about 135-140 db. A jet engine at 75 feet produces a noise level of 140 db. Construction equipment usually ranges from 70 to 110 db. See table 5. Figure 30 provides typical ranges of safe and dangerous exposures as a function of noise intensity and duration. In the working environment, there is no indication of hearing damage at noise levels less than 75 db over 8 hours.

After a relatively short exposure to excessive noise, the worker may have a temporary loss of hearing known as "noise induced temporary threshhold shift" or NITTS. However, the individual's pre-exposure hearing capability is restored shortly after the noise ceases. NIPTS or "noise induced permanent threshhold shift" is irreversible and is caused by prolonged exposure. It is generally associated with the destruction of the inner ear's (cochlea) hair or sense cells (see figure 31) most often caused at high frequencies (maximum damage is sustained at about 4000 hz). Hearing loss generally results from ignorance and neglect whereas blast deafness is often accidental. The resulting "hearing impairment" is that level where the individual begins to experience hearing difficulties in everyday life (159). Figure

Effect (1)	MODERATE level of risk (db) (2)	APPRECIABLE level of risk (db) (3)
Hearing damage risk	70	90
Speech interference	45	60
Sleep interference	40	70
Physiological Stress	--	90
Startle	--	110
Annoyance	40	60
Task interference	55	75

TABLE 4

Noise Level Criteria For Impact Evaluation (65).

Source	db
Drilling underground	110-130
Automatic punch press at 3 feet	110
Jaw crusher	110
Screw Machines, air drills	90-100
Heavy trucks at 20 ft	90
Automobiles at 20 ft	75
Noisy office	70
Average Office, noisy home	40- 60
Conversational speech at 3 feet	60
Very quiet home, whisper at 5 feet	20- 40

TABLE 5

Typical Noise Intensity Levels Of Various Sources (153).

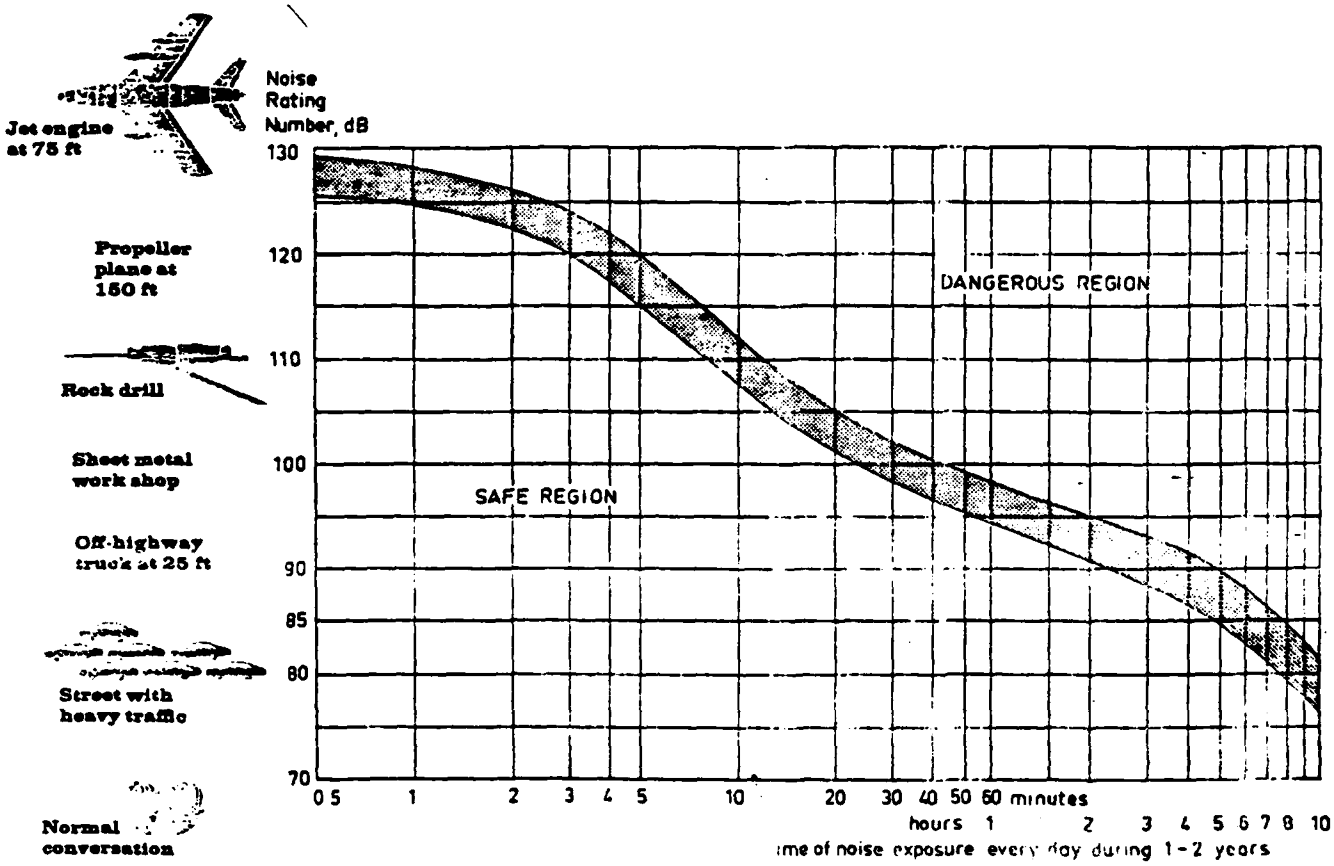


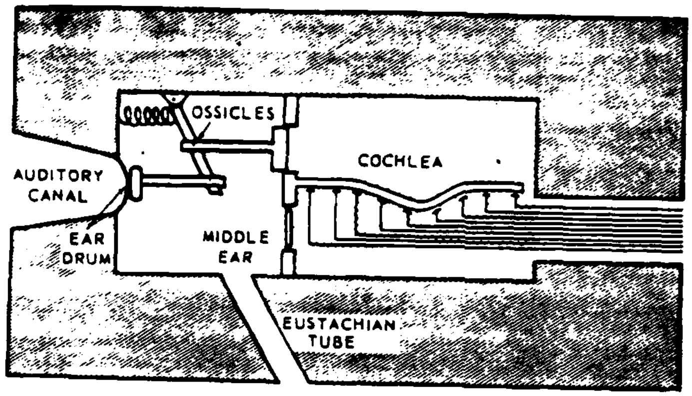
FIGURE 30

Permissible Daily Exposure Times For A Person Without Ear Protection Exposed To Noise is measured by Noise Rating Numbers shown in the figure. At a noise rating of 130 db, there is a danger of permanent ear damage after a very short exposure of some seconds (94).

FIGURE 31

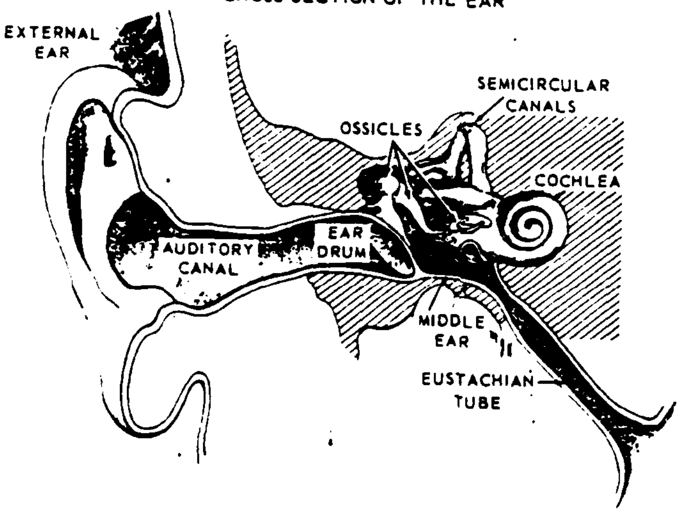
ANATOMY OF THE EAR

a. SCHEMATIC OF THE EAR



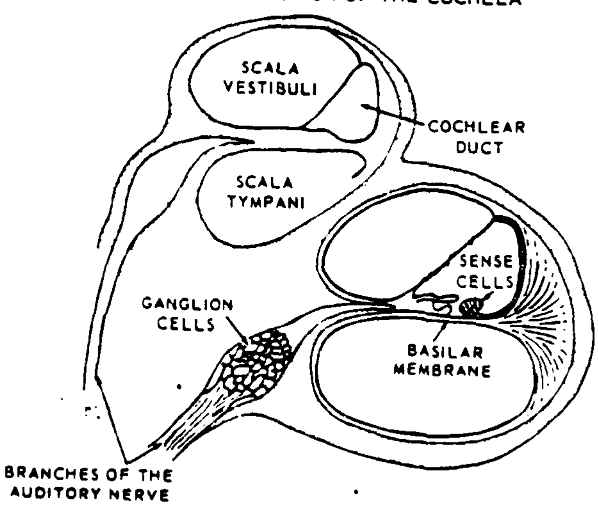
A. Mechanical schematic of the major parts of the ear.

b. CROSS-SECTION OF THE EAR



B. Simplified drawing of the ear. The eardrum is a tough thin mem- - brane that transmits pressure changes from the external ear to the middle ear bones or ossicles. The ossicles are the smallest bones in the human body.

c. CROSS-SECTION OF THE COCHLEA



C. The cochlea is presented in magnified section. The sense cells, about 30,000 in all, can transmit this information to the brain via the auditory nerve.

Source: (150)

32 illustrates hearing loss by miners as a function of the number of years of noise exposure at various frequencies.

A study of almost 125,000 construction workers in Sweden showed that about 7% suffered from serious hearing loss probably induced by noise. Particularly high numbers were found among rockblasters, sheetmetal workers and carpenters. Tool repair workers, heavy equipment operators, and concrete workers also exhibited a high rate of hearing loss (51) (147). In the Federal Republic of Germany, noise induced hearing loss was most frequently found among heavy construction equipment operators and crane operators (51) (38). Hearing loss may comprise of up to one half of all occupational diseases in construction workers claiming compensation (51) (61).

There is evidence that noise causes other substantial physiological damage to the body in addition to hearing impairment. Prolonged exposure to high noise can cause a persistent increase in blood pressure as well as a constriction of blood vessels located in the peripheral regions of the body such as fingers, toes and earlobes (154) (83) (52). This vasoconstriction may eventually lead to heart disease. Steelworkers exposed to a noise level of 95 db, particularly, have been found to have high incidents of heart rate irregularities (154) (73) (52) (27).

Too much noise can result in "noise sickness". In examining workers subjected to excessive noise, investigators found numerous complaints of irritation, headaches, memory

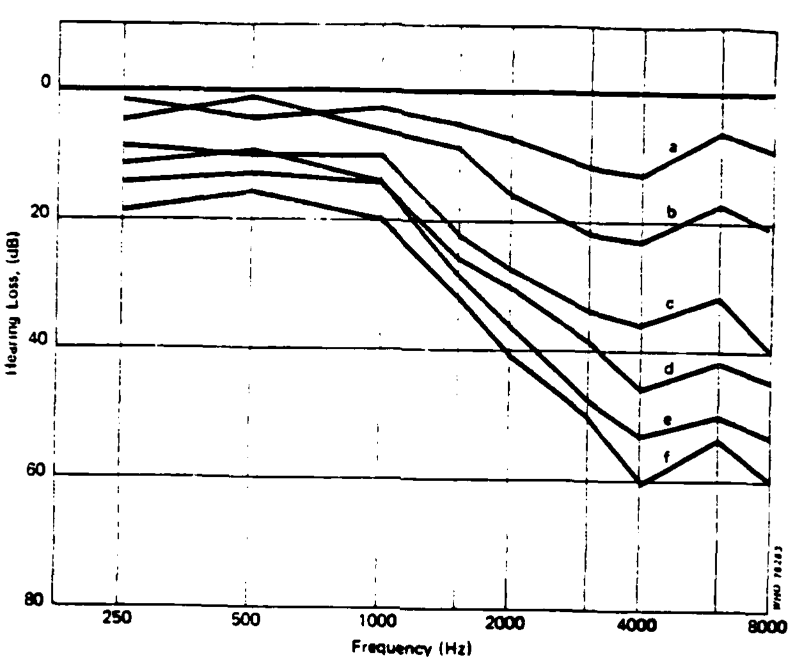


FIGURE 32

Hearing Loss As A Function Of Number Of Years Of Noise Exposure. Mean audiograms for 203 miners, best ear tested (159).

a < 1 year
b 1-5 years
c 6-10 years
d 11-20 years
e 21-30 years
f > 30 years

failure, drowsiness, increased fatigue, and sexual impotence which increased with time on the job (2) (52) (27). With high frequency noise of an intensity of 140-150 db, pain was noted in the eyes and ears.

Noise intensity appears to be the most influential factor. When it is increased, there is an increase in the frequency of complaints, particularly of general irritabilty. Pulse noises, as opposed to stable ones, raise more negative complaints. Other effects include changes in breathing pattern, more rapid pulse, sweating and muscle tension. Figures 33 and 34 show changes in heart and respiratory rates under the influence of noise.

In a 1961 experiment subjects were exposed to noise in the 1600-2000 hz frequency with intensities of 80, 70 and 60 db. After the 80 db intensity exposure the subjects' strength was found to be reduced by 25% of the original value, fatigue increased by 11% and the amount of work performed after the noise exposure was significantly decreased (2).

Noise also affects vision. Noise at a frequency of 800-2000 hz of medium to great loudness reduces the light sensitivity of the retina. For example, the noise of an airplane engine (115 db) reduces the sensitivity of scotopic vision (i.e. vision in dim light) by 20% when compared to vision during silence. The stronger the noise intensity, the lower the stability of clear vision, and consequently, decreased work productivity (2).

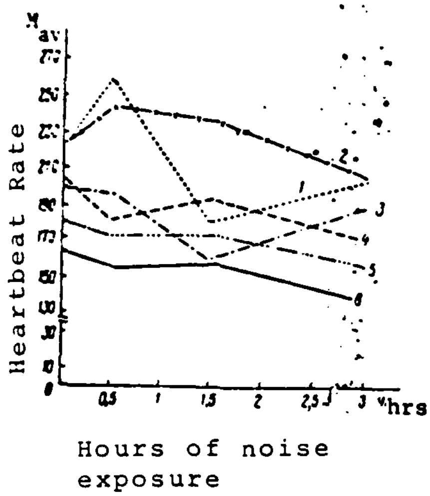


FIGURE 33

Heartbeat rate under the influence of noise (120 db)(2).

Days of experiment:
1-first
2-second
3-fifth
4-sixteenth
5-twenty-sixth
6-thirty-ninth

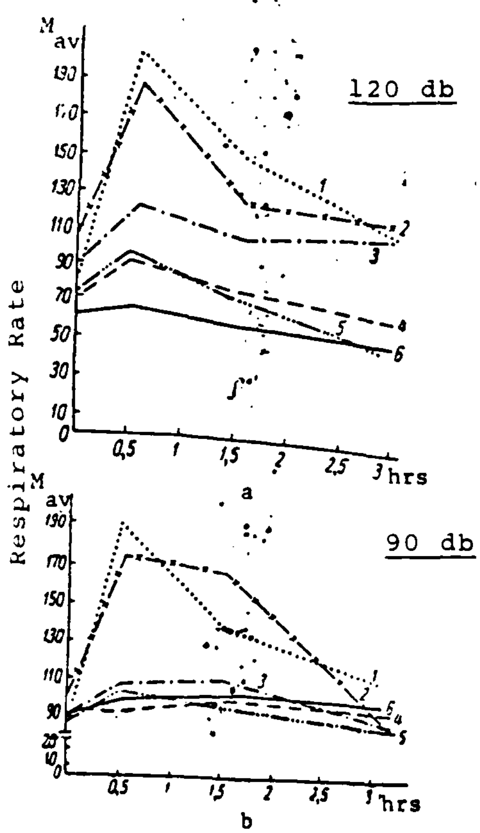


FIGURE 34

Respiratory rate under the influence of noise with an intensity of (a) 120 db and (b) 90 db. Legend same as figure 33. (2).

(A)

(B)

Intense noise ranging from 95 to 120 db may disturb the sense of balance if there is unequal stimulation of both ears. Sound signals of excessive force can cause "overstress" and "breakdown". Certain noises, particularly, impulse ones, may cause a startle reflex even at a low level. This occurs in order to prepare for action in the event of a dangerous situation signalled by the sound. The reflex action may be accompanied by a fright reaction, where effects to the circulatory system become more pronounced (111) (159).

Sleep interference is another product of noise, being affected by it in two ways: firstly, noise delays the onset of sleep, and secondly, it causes a shift in the usual sleep stages. Reports show that levels of 40 db may wake as much as 25% of the sleeping population, 45 db may keep 20% from immediately falling asleep, 70 db may wake more than 50% of the population while just less than 50% would be kept from falling asleep in 70 db noise (65) (154). By disrupting sleep, noise interferes with the normal recuperative processes of the body and could conceivably lessen the body's resistance to disease or physical stress. Alertness is reduced, with consequential impaired performance. Interestingly, under certain conditions to be discussed, the effects of noise may actually be beneficial to sleep loss.

Estimates are that 34,000,000 people suffer a total of several hundred hours of speech interference yearly as a result of construction noise in the United States. The degree of conversation depends on how well speech can be heard over background noise. The relative intensity is usually expressed as the "signal to noise ratio". Figure 35 shows the comfortable level that two workers can speak to one another. Under these conditions, about 75% of the isolated words can be heard correctly. The figure shows that with background noise of 90 db, two workers would have to stand ½ foot apart to be heard. If given the option, it is better to move closer and talk with a more normal voice because voice distortion when shouting offsets the advantage of increased intensity (124). For normal conversation, background noise should be less than 45 db. Even more stringent noise control measures are required when communicating by phone or radio due to the lack of seeing the speaker (particularly lip movement) and because noise, itself, is also transmitted over the equipment, i.e. speaking into a telephone should be louder than when conversing in person with the same background noise.

The lessened degree of communication resulting from noise interference also affects safety. Danger signals are less audible and warning shouts are all too often never heard. Workers become less efficient, less alert, and more careless. Even when a particular word is masked, the word or sentence in which it is a part may be sufficient to convey the meaning. However, the energy and effort required to be more attentive and interpret the sounds induce more fati-

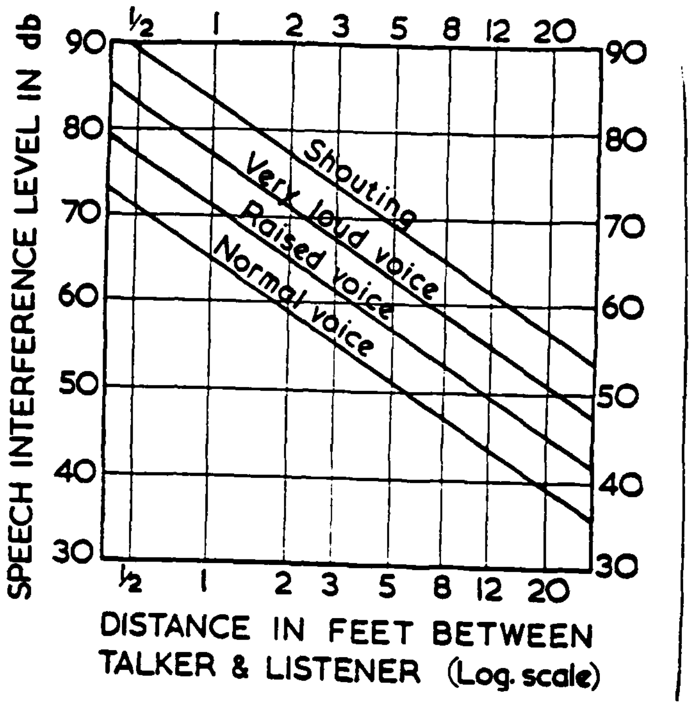


FIGURE 35

Speech Interference Levels Which Permit Talkers At Various Distances To Speak To Each Other With Only Slight Difficulty. Points below a line corresponding to the loudness of the voice are acceptable. Points above the line are not (113)(124).

que in the listener. See figure 36 which associates sound intensity, communicating distance and degree of intelligibility. Figures 37 A & B illustrate speech intelligibility as a factor of signal to noise ratio.

The value of 40 db is an estimate of the level of noise required to initiate annoyance, however, the nature of the sound as well as the idiosyncracies of the receiver dictate where the annoyance threshold actually lies. Annoyance appears to grow with increasing intensity, loudness and higher frequency. See table 6 which illustrates the degradation of attention as a factor of intensity and time. The working capacity is most sharply altered after the initial activation of the noise. Later, as the noise continues, concentration of attention increases. Any reduction of attention is dangerous in dynamic work situations as in the case of many construction operations.

Although they generally cause less deafness and speech interference, sounds which are intermittent or randomly occuring are often considered more annoying than steady, continuous, or unchanging noises. This is because each time the noise occurs, the worker's mind momentarily wanders. Likewise, a sound which is moving, rather than fixed in a single location, is considered the more annoying of the two situations. Characteristics of annoying noise are speech masking, deprivation of sleep or relaxation, distraction, and startle. Some sounds are particularly annoying to an individual such

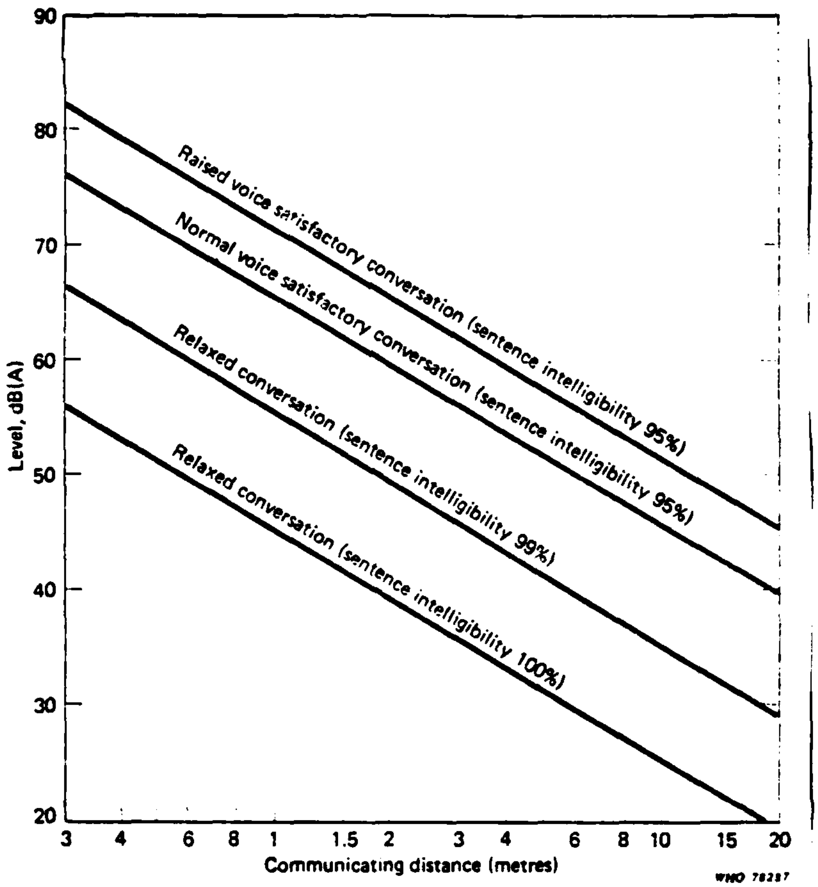


FIGURE 36

Maximum Distance Outdoors Over Which Conversation Is Considered To Be Satisfactorilly Intelligible In Steady Noise (159).

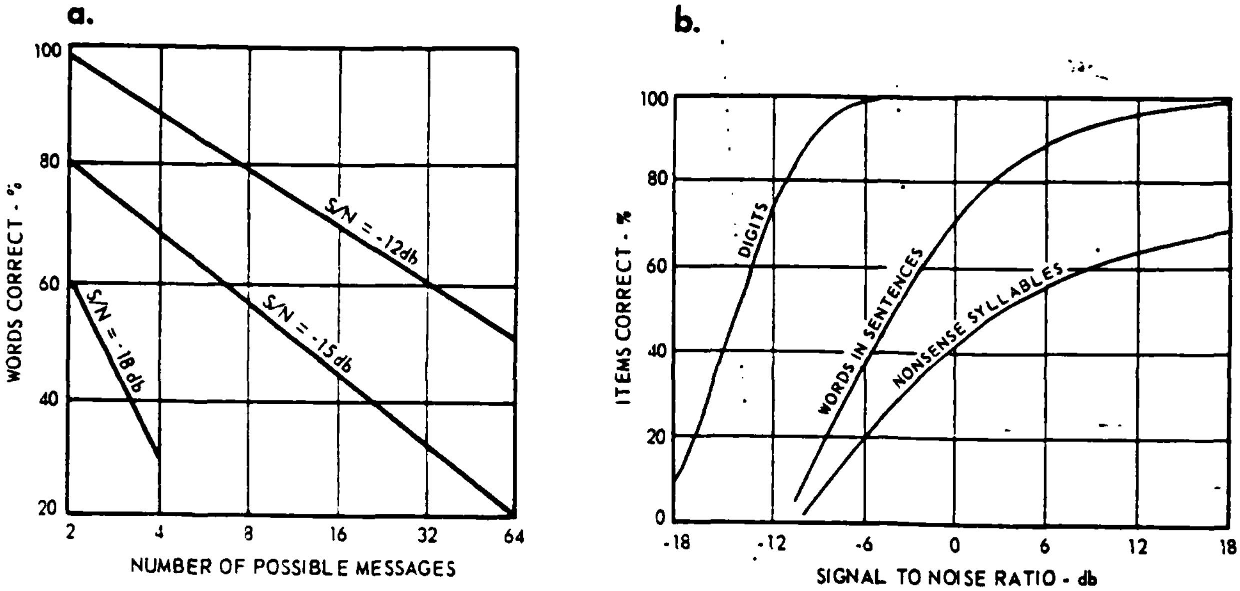


FIGURE 37

Sound Perception: Speech Intelligibility

(A) As the number of messages (standard, two syllable words) increases from 2 to 64, the % of correct reports about the messages drops. The relationship is poorer when the signal to noise ratio is lower.

(B) Single numbers (digits) are detected correctly more easily than are words and sentences, and words in sentences are detected correctly more easily than nonsense syllables (93)(108)(123).

scratching on a blackboard, or where a childhood encounter may cause a particular sound to psychologically affect the individual resulting in uneasiness, discomfort, sweat, rapid pulse, and muscle tension.

It has been inferred that noise is responsible for many needless industrial accidents due to its effect on startle, attentiveness, annoyance and ability to hear warnings or directions. As a result of the potential dangers caused by noise, in 1970 the Occupational Safety and Health Act was enacted, stipulating that for an 8 hour work day, a worker may not be exposed to more than 90 db. Table 7 summarizes the permissible noise exposures that the act allows. Unfortunately, there are few, if any, known studies, particularly in the construction industry, which associate accidents and "near misses" to noise. Such a study is recommended for future research.

The effect of noise on performance has been studied primarily in laboratories rather than in real life situations. However, there are indications that under certain circumstances, excessive noise can be <u>beneficial</u> to the worker. Some experiments have demonstrated that intense noise may actually improve performance in persons who have been without sleep and are tired, even when they are performing a task that would be highly affected by noise if sleep had been normal (31) (152) (159). Woodhead (158) (159) demonstrated that noise adversely affects memorization/problem solving

Intensity, dB	Reduction of concentration of attention			
	Initial values	After 30 min.	After 60 min.	After 120 min.
100	31,2	23,2	20,7	15,6
90	18,9	18,2	15,8	10,4
80	16,1	14,6	10,2	8,1
70	9,5	10,4	5,8	5,1
60	5,7	5,0	1,7	1,0

*Commas represent decimal points.

TABLE 6

Reduction Of Concentration Of Attention (in %) In Comparison With Initial Value (2).

Duration per day, in hours (1)	Sound level, slow response, in dbA (2)
8	90
6	92
4	95
3	97
2	100
1-1/2	102
1	105
1/2	110
1/4 or less	115

TABLE 7

Occupational Safety And Health Act Of 1970 Permissible Noise Exposures (65).

combination tasks, yet when noise is introduced during the calculation phase, performance actually improved. Studies by Hockey (67) (159) showed that at times, the introduction of noise during high priority performance helped, while during low priority performance, it hindered. Bryan and Colyer (19) (159) reported that under noisy conditions, people with high intelligence showed a decrease in mental task performance whereas the performance of those with average intelligence actually improved. Broadbent (159) (15) found that when individuals perform monotonous activities, noise is likely to reduce the accuracy rather than the quantity of work performed, and that noise, in general, increases human error (16).

Errors in industry mean spoiled work and higher costs. Broadbent and Little (16) found that by applying accoustical treatment to an industrial setting, noise was reduced from 100 to 90 db. After 6 weeks they found a significant reduction in waste and operator errors, but no effect on worker output.

Figure 38 summarizes the principal harmful effects of noise on man as it effects hearing ability, conversation ability, and work interference. These are despite man's mental noise filter which, according to Broadbent (15) (159), naturally screens out useless information such as noise. The filter, however, has the following limitations:

(A) Over a period of time, it tends to reject or

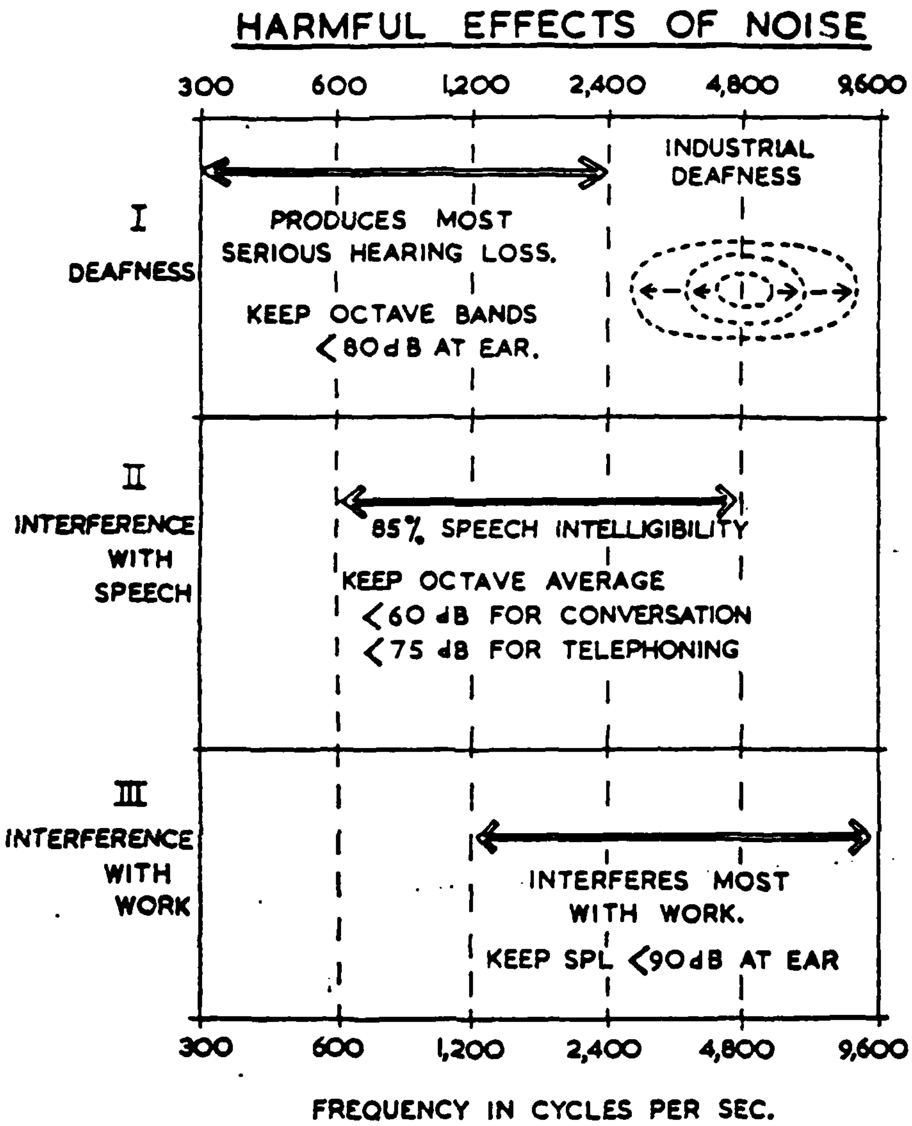


FIGURE 38

The Principal Harmful Effects Of Prolonged Noise Upon Man. The top right hand part of the figure illustrates how industrial deafness tends to start at a frequency of about 5000 hz and gradually spreads up and down the frequency spectrum (124).

ignore unchanging signals regardless of importance.

(B) The filter's ability to discriminate may be hindered depending on the worker's state of arousal, stress, or fatigue.

(C) The filter can be overridden by irrelevant stimuli which demand attention because of novelty, intensity, unpredictability (such as the start of an unexpected noise), and so forth.

RECOMMENDATIONS

It may be assumed that no matter how hard an individual tries to ignore, concentrate on, or otherwise be affected by noise, noise will affect the way a worker does things, for better or for worse. Because of the undesired effects of noise, however, additional outside intervention by management is required, and the following recommendations are made:

(1) SELF POLICING OF NOISE LEVELS is required and should consist of periodic weekly testing with noise monitoring equipment as well as when added noise sources are started and stopped.

(2) Construction equipment is often poorly silenced and maintained, and operations are frequently done with little or no regard for environmental noise considerations. NOISE SHOULD BE ISOLATED BY LIMITING THE NUMBER OF SOURCES, BY PHYS-

ICALLY SEPARATING THE NOISE SOURCE FROM THE PEOPLE through barriers and insulation, and by CHANGING WORK METHODS to include a reduction in the number of hours of exposure, education of workers, and use of ear protection. Tables 8 and 9 show how noise can be reduced by performing some simple control techniques on various construction noise sources.

(3) RESEARCH INTO LOW NOISE EMISSION PRODUCTS SHOULD BE ENCOURAGED as well as information to owners and users on current availability and the benefits those products achieve.

(4) CONSIDER USE OF QUIETER EQUIPMENT. For example, conventional piledrivers create 100 db of noise as the hammer strikes the pile. Consider the use of vibratory pile drivers which are barely audible except for the sound of the equipment's gasoline engines (65). Use of exhaust mufflers, intake silencers, and enclosures on existing equipment will also result in reduced noise.

(5) When working inside, some low intensity BACKGROUND MUSIC is advisable as a source of arousal for the worker.

(6) ENCOURAGE INDUSTRIAL STANDARDS ENFORCEMENT FOR NOISE EMISSIONS. Such enforcement would encourage continued research and development of quiet equipment.

(7) Ensure workers receive PROPER TRAINING on the effects of noise emissions, and ENFORCE REGULATIONS mandating that they properly use effective noise protection.

(8) If generation of noise in inevitable, intermittent noise exposure is less damaging to hearing than is

Source (1)	Control techniques (2)	Probable noise reduction, in dbA (3)
Engine		
Exhaust	Improved muffler	10
Casing	Improved design of block	2
	Enclosure	10
Fan (cooling)	Redesign	5
	Silencers, ducts, and mufflers	5
Intake	Silencers	5
Transmission	Redesign, new materials	7
	Enclosure	7
Hydraulics	Redesign, new materials	7
	Enclosure	10
Exhaust	Muffler	5-10
Tool-work	Enclosure	7-20

TABLE 8

Noise Control For Construction Equipment (76).

TABLE 9

Representitive Levels Of Noise Generated
By Construction Equipment (65)

CONVENTIONAL PILE DRIVING	
(impact of hammer on pile)	100 db @ 50 ft
VIBRATORY PILE DRIVING	
(vibrations at resonance)	barely audible
LARGE PNEUMATIC TOOLS	
(high pressure exhaust and impact against work)	80 - 97 db @ 50 ft
(using muffler)	10 db reduction
(using barrier)	3-10 db reduction
HAND HELD PNEUMATIC TOOLS	
(exhaust & impact)	84 - 88 db @ 50 ft
(using muffler)	5 db reduction
EARTH MOVING EQUIPMENT*	73 - 96 db @ 50 ft
MATERIAL HANDLING EQUIPMENT*	75 - 90 db @ 50 ft
STATIONARY EQUIPMENT/PUMPS,GENS.	70 - 80 db @ 50 ft

*see table 8 for potential reductions

continuous exposure. ROTATING WORKERS in and out of continuous noise situations is encouraged.

(10) PROPERLY FITTING HEARING PROTECTORS may reduce noise by as much as 35 db without depriving the worker of useful communication. Workers can use ear protection similar to that used by airport workers which filter out some frequencies and not others.

(10) PRE-EMPLOYMENT AND SUBSEQUENT AUDIOGRAMS SHOULD BE PERFORMED to establish a record of any additional hearing losses incurred so that corrective action may be taken. Since hearing loss is often permanent, immediate steps should be taken to prevent further deterioration when hearing loss is noted.

(11) PROVIDE ACOUSTICAL TREATMENT to the interiors of shops, garages and other applicable work areas to reduce noise intensities.

(12) RESEARCH IS ENCOURAGED on trends among equipment noise output, types and locations of projects emitting noise, characteristics of noise-exposed workers, knowledge of workers on noise and comparisons between noisy and improved work situations.

It has been demonstrated that noise affects workers' health, their well-being, and their performance. It is something too often overlooked by workers and management alike, taken for granted, or not taken seriously. It is important to all concerned that noise control be effectively enforced. Long term savings should more than offset any initial outfitting or implementation costs.

7. VIBRATION

GENERAL

Vibrations are another aspect of the occupational environment that merits investigation. Approximately 6,800,000 American workers are exposed to whole body vibration. Of these, some 500,000 are heavy equipment operators, 1,000,000 are truck drivers, 2,800,000 operate farm vehicles, and 51,000 are school bus drivers. Another 1,200,000 workers are exposed to hand-arm (segmented) vibration (151).

Guignard and Irving (56) (149) admit it is difficult to provide a strict scientific definition of "vibration" but offer the following:

> a fluctuating, mechanical disturbance, periodic or transient, which the human body perceives by the senses other than hearing. More simply, vibration is felt rather than heard...

Poulton (124) states that "vibration differs from sound in that it is transmitted through solid structures which are in contact with each other. Sound is carried by the air." Helander (63) describes it as:

> motion (oscillating, reciprocating, or otherwise) that forces a body or medium out of a position or state of equilibrium. It generally is measured in the terms of frequency (cycles per second or hz)...amplitude...velocity...and acceleration.

Although vibration is frequently and unintentionally self-induced during the physical activity such as running, walking and swimming, it is usually regarded as an externally applied stress. External vibrations have impacted on man's well-being from the days when he first rode atop animals' backs and invented the wheel. Vibration concerns have continued into the Space Age as evidenced by human factors engineers who continually study vibrations induced by the space shuttle and modern land transportation and industrial equipment.

There are three basic types of human exposure to vibration: (1) vibrations transmitted simultaneously to the whole body surface or to substantial parts of it; (2) vibrations submitted to the whole body through supporting surfaces such as feet (when standing) or buttocks (when sitting); and (3) those vibrations (known segmental vibration) applied to a specific part of the body such as arm or head.

Human experiments in vibration are inherently dangerous. Most laboratory studies start with purposely low levels of force, which are increased only to the point of intolerance as controlled by the subjects. The use of experimental animals in place of humans has been found to be of limited value, as many can tolerate vibrations to a greater extent than humans can. This capability is probably due to the difference in placement of limbs, difference in body size, difference in organ suspension, and so forth. One exception is that black bears have been used in ejection seat studies, as bears come close to approximating the size and the body mass distribution of man (150).

Individuals cannot tolerate some kinds of vibration for long periods of time without real danger to their health and well-being and without adversely affecting their overall performance. As stated previously, construction workers are one of the largest groups exposed to vibrations by virtue of the equipment they operate, tools they use, and the environment in which they work. There is a dearth of study on vibrations and a subsequent lack of information and training imparted to those within the construction trades. It is therefore important that mangement learn and realize, from what little research has been conducted, the detrimental effects that vibrations may have on workers, and consequently, on their project.

EFFECTS

Clayberg (23) (132) reported in 1940 that army officers who rode for prolonged periods "in jeeps over rough roads developed severe lower back pains causing retirement from service with substantial diagnosis of intervertebral disc hernia or rupture." In 1950, Fishbein (41) (132) reported some 45 disorders considered to be caused or aggravated by vibration and vehicle jolts. Weaver (149) dubs vibration as "one of the most stressful environmental agents which man encounters." Poulton (124) warns that high frequency vibrations at high amplitude will kill laboratory animals and produce severe pain and internal bleeding in humans. Yet, some vibrations are considered to be pleasant and relaxing, and in some cases, are featured by major hotels as an extra incentive to stay at the facility.

Figure 39 depicts the human body as a system of masses, springs, and dampers. As the entire body is meant to vibrate, the tendency is for all of the various parts not to vibrate in unison (98). A wide range of vibration frequencies excites various parts of the body to varying degrees. Thus, the buttocks may be the principal course of reaction to one frequency of motion and the thorax to another (45).

Figure 40 shows the effects of a subject vibrating while standing on a vibrating platform. The human body resonates (i.e. setting in concert with externally generated vibrations, actually amplifying the resultant vibrations) vertically at frequencies between 3 and 6 hz (124). The heart is believed to have a natural resonant frequency of 7 hz (60). The upper torso generally resonates at 5 hz, the head-shoulder system resonates in the 20-30 hz range, and the eyeballs in the 60-80 hz range (71) (25). The brain is suspended in fluid in a rigid skull and also has a resonant frequency at which it is sensitive to vibration. Sensory nerve fibers of the body may also affect the brain as they become stimulated by the outside vibrations.

Figure 41 illustrates that the resonant frequency of the human body for a horizontal vibration lies between 1 and

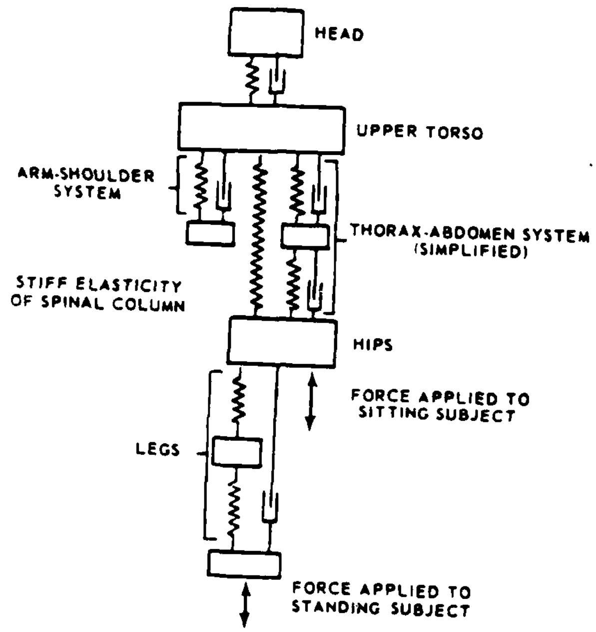


FIGURE 39

The Human Body As A System Of Masses, Springs, And Dampers (26)(93)(150).

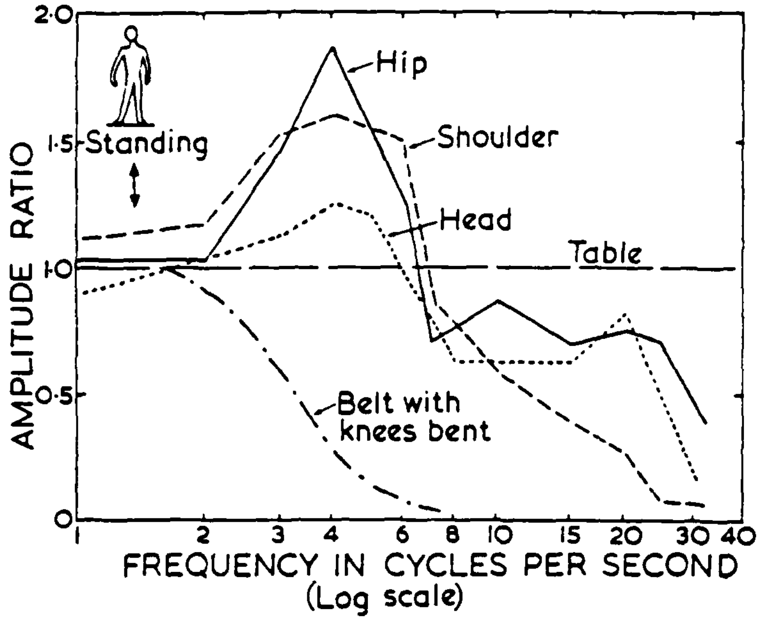


FIGURE 40

The Amplitude Of Vertical Vibration Of Various Parts Of The Body Of 1 Man Standing On A Table Vibrating Vertically. The amplitude is expressed as a ratio of the amplitude of the part of the body to the amplitude of vibration of the table. At 5 hz the amplitude of vibration of the head is larger than the amplitude of vibration of the table. The shoulder and hip vibrate even more at this frequency. Bent legs absorb most of the vibration (49)(124).

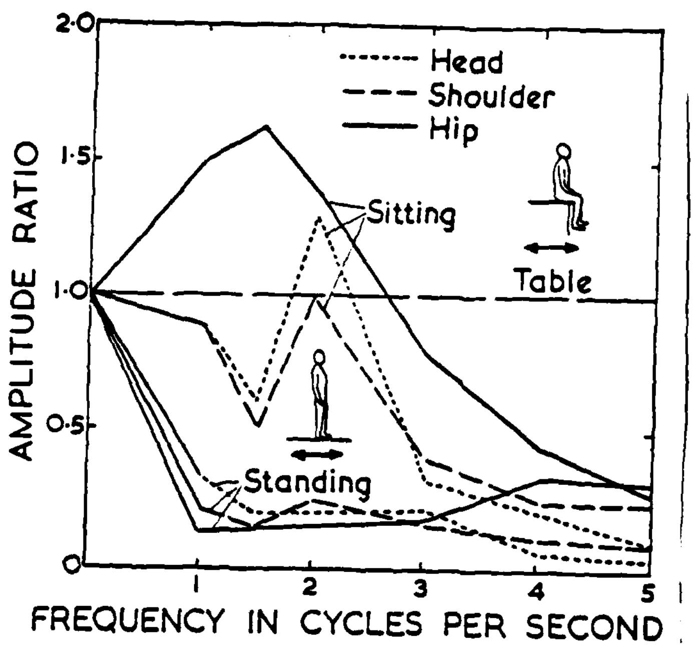


FIGURE 41

The Amplitude Of Horizontal Vibration Of Various Parts Of The Body Of 1 Man (a) Sitting And (b) Standing On A Table Vibrating Horizontally In The Direction Shown. Amplitude is expressed as a ratio of the amplitude of the part of the body to the amplitude of vibration of the table. At 2 hz the amplitude of vibration of the head is greater than the amplitude of vibration of the table when the subject is seated. The legs of a standing person reduce the amplitude of vibration of his body and head to about 1/5 or less of the amplitude of vibration of the table (49)(124).

3 hz (the horizontal resonance of the body). Most hand tools vibrate at frquencies of 40 to 50 hz. At these frequencies, the amplitude of vibration is reduced to about .01% of the source frequency by the time it reaches the head. The arm alone reduces it to about 1% with additional reduction in the shoulders and neck (49)(124).

The vibratory "dose" that a worker receives depends on (151):

(a) The worker orientation and degree of body contact with the source;

(b) Available filtering by clothing, cushions, tires, etc.;

(c) Multiplicity of vibrating sources (2 engines, etc.);

(d) Vehicle speed and terrain;

(e) Worker age, mass and job exposure.

In discussing vibratory effects on humans, it is common to refer to the standard X,Y,Z coordinate system as shown in figure 42. With the heart being at the origin, the x-axis passes from the back to the chest, the y-axis transverses from the right to left side, and the z-axis passes from the feet (or buttocks) through the head (72) (149). The z axis appears to be the most significant one in terms of effect on the body.

Sinusoidal vibration is generally uncomfortable above 0.1 9 ("g" refers to acceleration or the rate at which the

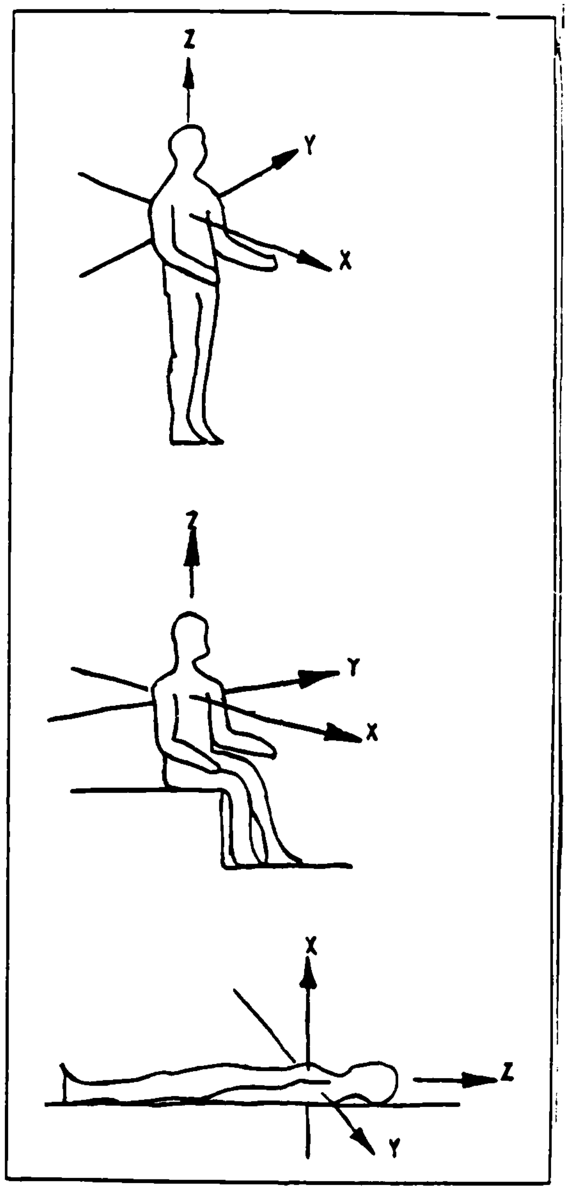


FIGURE 42

Directions Of Co-ordinate System For Mechanical Vibrations Influencing Humans (72)(149).

velocity or vibratory motion changes direction). Sinusoidal vibration is painful at 1 g and injurious to the body above 2 g if maintained for longer that a few cycles. Chest pain may occur at 5 hz and balance and the ability to sit erect will be impaired, resulting in physical fatigue. Even very low frequencies will have some effect: vibration at 1 hz results in motion sickness and at 2 hz sleepiness. Above 10 hz visual acuity and coordination will be impaired (63). Vibrations above 30 hz are likely to be absorbed at the point of contact (feet, buttocks, etc.) and not transmitted elsewhere (53). However, Cope (30) (60) adds the following:

> In general, at a frequency of 0.1 cps, the head vibrates at somewhat near the amplitude of the seat, but, as frequency increases, the amplitude of the head increases and reaches a peak somewhere between 3 and 6 cps. At this frequency - the head vibrates at an amplitude equal to 150-300% of the seat amplitude. Seat - head transmission decreases progressively at the higher frequencies, so that when one has reached 70 cps, only about 10% of the amplitude of the seat vibration may be expected to reach the head.

Figure 43 summarizes the responses of 10 individuals exposed to vertical sinusoidal vibrations of varying amplitudes. They were seated on hard seats, restrained by a belt and harness. The vertical bars show the approximate magnitude of the following groups of symptoms:

<u>Chest</u>: (cross-hatch) respiratory difficulty, pain breath holding.

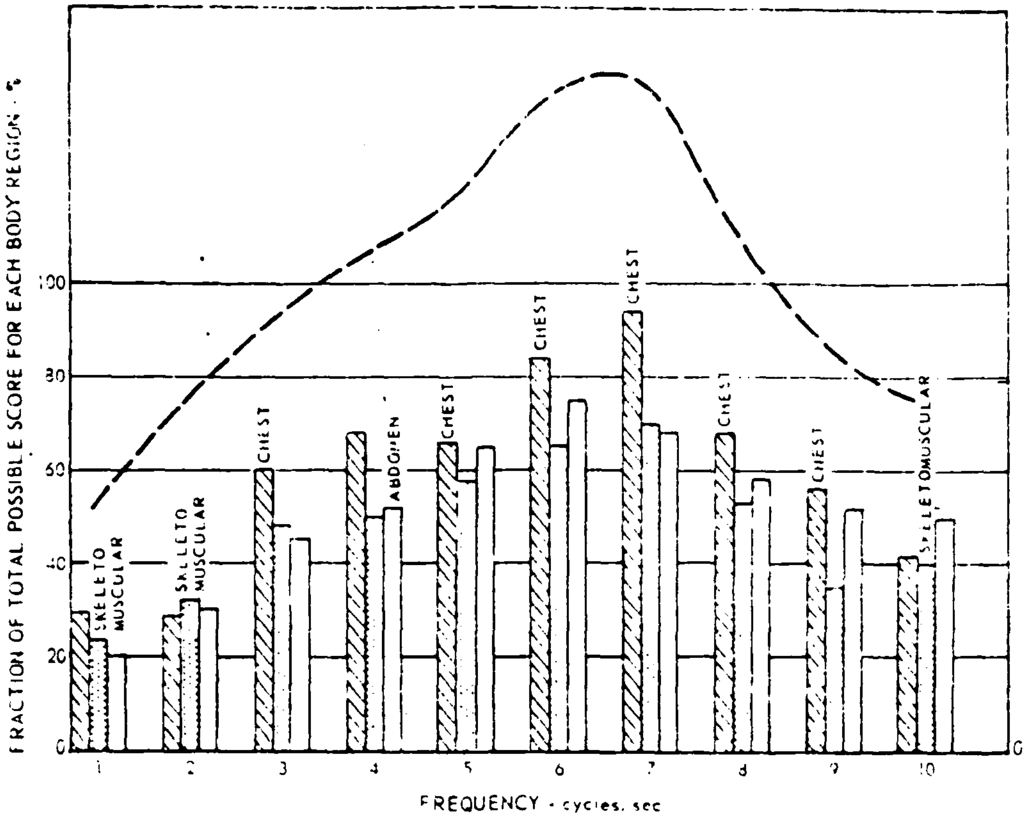


FIGURE 43

Subject Response To Vibration (36)(150).

Skeletomuscular: (dotted bars) muscle pain, back pain, general discomfort.

Abdomen: (open bars) contraction, pain.

The words above each set of bars state what symptom sets the limit for voluntary tolerance for that particular frequency (96) (150).

The unique feature about vibration, distinguishing it from other motion, appears to be its oscillatory nature. This oscillary characteristic may be a most important variable in determining the degree of decrement in worker performance.

Vibrations degrade human comfort, efficiency, safety and health. They occur at different or concurrent times within the body and degrade human performance in the following ways:

(a) Motion of the eyes and head blur vision and vision fixation;

(b) The vibratory motion affects manual control ability;

(c) Vibration impairs tracking (or concentration) ability proportional to the vibration amplitude;

(d) Vibrations have little effect on reaction time, monitoring, and pattern recognition (53) (60) (68) (98).

Research into the medical histories of truck drivers, bus drivers and air traffic controllers (all seated positions) showed that truck drivers had a significantly higher degree of bone deformities and vertebrae pain, hemorrhoids, kidney disease, and peptic ulcer. There is twice the incidence of premature, degenerative deformities of the spinal column among long haul truck drivers than there is among bus drivers, probably due to the combination of increased exposure to whole body vibration, faulty posture used to compensate for the vibration, and heavy manual work used by drivers in loading and unloading (63). Many operators of heavy construction equipment emphatically oppose regulations requiring them to use seat belts. They contend this will result in exposure to dangerous vibrations and oscillations they will absorb as a result of the tightened seat - buttocks interface. Their arguments are not without merit.

Workers who have operated hand-held vibratory tools for years at frequencies of 50 to 1000 hz may contact Raynaud's Disease (or Raynaud's Phenomenon, "white finger", or "white hand") where blood vessels supplying blood to the fingers constrict due to coldness, becoming white and numb. Hands become blue, swollen, and painful as frequencies are increased beyond 200 hz (55) (124).

Workers response to hand-held vibration is dependent upon:(a) the vibration frequency, (b) the vibration amplitude, (c) the duration of exposure per working day, (d) the length and frequency of rest periods and whether the tool is held or laid aside during this time, (e) the magnitude and

and direction of forces applied by the operator through the hands to the tool or workpiece, (f) the posture of the hand, and (g) the type of vibrating machinery or hand tool. Further, the severity is highly influenced by (a) the direction of the vibration transmitted to the hand, (b) climatic conditons, (c) the method of working and degree of operator skill and, (d) the worker's peripheral circulation (70) (149).

In 1862, Doctor Maurice Raynaud described Raynaud's disease as follows:

> ...one or many fingers becoming pale and cold all at once. It is the phenomenon known under the name of the "dead finger". The attack is indolent, the duration varying from a few minutes to many hours. The determining cause is often the impression of cold. The skin of the affected parts assumes a dead white colour; it appears completely ex-sanguine. The cutaneous sensibility becomes blunted, then annihilated (149).

Drogicina and Razumov (37) (149) characterize Raynaud's Disease in the following way:

> ...most characteristic symptoms are impairment of local circulation, and hypersensitivity of the hands. Perceived numbness of the fingers, particularly after the end of a working day or at night, is one of the first symptoms, followed by muscular pain in the shoulder joints and increased sensitivity to cold. As a result of the exposure to cold, vasospasm occurs in the hands and the fingers become white and eventually blue. After extensive exposure, the external appearance of the fingers and hand change. At this stage, the hand takes on a clubbed appearance and the skin temperature usually drops...

Reynolds and Jokel (149)(127) postulate that:

> ...since the hand is a highly complex continuous elastic system, it is capable of tremendous damping ability. This damping ability allows large amounts of energy to be dissipated "due to the relative motions between the tissues in them." This is presumed to have two effects- irritation and heat. As stated by (the authors) both of these (effects) will stimulate an increase in the flow of blood into the area and can result in a tingling or burning sensation...(which) will result in redness of the skin and swelling...

Reynolds an Jokel further noted that the disease's presence is greater in colder climates and that some individuals are more susceptible than others. The cause of the disease is unknown, but factors appear to be cold exposure and general body or local hand cooling and vibratory stimulation (149) (103). McGrath and Penney (103) (149) explain that the direct effects that vibrations have on the hands to cause the disease include: (a) a disturbance of the vessel walls or of the peripheral nerves caused by the vibration energy, (b) spasms and constrictions of the blood vessels and (c) clotting caused by the recoil kicks of the tools into the hand. The seriousness of white fingers has been debated. Injuries Advisory Council of Great Britain (149) decided that "at worse, vibration-induced white fingers would lead to only temporary inconvenience and possibly a change in employment and a substantial loss of earnings." The condition will usually disappear after the fingers are warmed; however, there have been some cases of permanent disability (137) (149). Walton (148) (149) notes that "cessation of exposure rarely results in complete recovery but most often will remain unchanged or show only a slow progression."

Another disease that has been attributed to vibrations is motor neuron disease. That portion of the nervous system directly concerned with transmitting signals to the muscles and glands is called the "motor division" of the nervous system (58). From 1972 to 1981 over 1100 patients with clinically confirmed "motor neuron disease" sought treatment at the Sanders Medical Research Foundation (46). Among them were 85 male adults whose symptoms had begun prior to the age of 45. Gallagher and Sanders sent questionaires to the 85 and received 50 replies. Of these, 12 (or 24%) reported having operated an air driven hammer or drill prior to the onset of the disease. Table 10 summarizes the patients' backgrounds and the effects that pneumatic tool use had on them. All workers exhibited contractions of the muscles of the extremities or trunk, or both, followed by a degeneration (atrophy) and weakness of the involved muscles. In all patients, the disease was progressive and fatal to five. There appears to be no clear relation between the degree of exposure to the vibrations from air driven tools and the severity of the disease. However, it is evident that there is no truly "localized" vibration. Vibrations supplied to one area are transmitted to other parts through bone structure and body tissue. Jackhammering is one example where the intensity of the vibrations to the hands is transmitted

Patient No.	Age at Onset (yr)	Occupation	Pneumatic Tool Use: Tool	Years of Use	Frequency of Use	Presenting Symptoms
1	28	Farming/ranching	Jackhammer	5 (?)	Occasional	Paresis, hand (PARALYSIS)
2	30	Construction	Large drill	1	Occasional	Paresis, fingers and arms
3	31	Machine operation	Light hammer	9	Frequent	Tremors, deltoids (reflexes)
4	33	Gasline construction	75 lb drill	4	Frequent	Paresis, leg
5	35	Construction	75 lb drill	< 1	Frequent	Paresis, hand
6	35	Construction	Jackhammer	12	Occasional	Paresis, hand
7	36	Mining	Drill	10 (?)	Frequent	Paresis, hand
8	37	Construction	Jackhammer	1	Occasional	Paresis, arm and leg
9	38	Construction	Jackhammer	8	Frequent	Paresis, both legs
10	42	Oil field drilling	Jackhammer	10 (?)	Occasional	Paresis, arm and leg
11	42	Construction	Jackhammer	10 (?)	Frequent	Paresis, arm and leg
12	42	Road construction	Jackhammer	< 1	Frequent	Paresis, both arms

TABLE 10

Occupational History and Symptoms of 12 Men With Motor Neuron Disease Developing Before 45 Years of Age (46).

to the shoulders and upper trunk (98).

Aside from hand held tools, construction workers are most likely exposed to low frequency, large amplitude, whole body vibrations. For track type equipment, the major frequencies range between 0.12 and 20 hz with peak accelerations of 0.01 to 0.25 g. About 25% of the frequencies peak in the 4 to 8 hz human body resonance band with 50% of the frequencies less than 0.15 hz. Rubber tire equipment has frequency peaks between 0.10 and 5.25 hz with peak acceleration from 0.04 to 0.13 g. Approximately 25% of the major peaks occur at frequencies less than 0.15 hz with 40% of the remainder being in the 2.12 to 2.6 hz range (151).

RECOMMENDATIONS

Vibration can impair man's performance. It can affect his physiological functioning and cause substantial damage to his body. The ailments worsen for the most part, with the degree of exposure. Excessive vibrations over time can result in death. For the sake of worker health and safety and on the job performance, the following recommendations are made:

(1) ENCOURAGE FURTHER RESEARCH into the field of vibrations as it affects construction workers, and the development of machines and equipment designed to operate at a safe vibration frequency.

(2) MAXIMIZE SPRING SUSPENSION AND OTHER PADDING

on equipment to assist in absorbing some of the vibrations experienced at the worker-equipment interface.

(3) Minimize vibrations and oscillations by TAKING PREVENTIVE MEASURES against them such as preventive maintenance of equipment and maintenance of haul roads.

(4) If feasible, ROTATE EQUIPMENT AND VIBRATORY TOOL OPERATORS in order to provide recuperation time between prolonged exposures.

(5) SUBSTITUTE EQUIPMENT FOR MANPOWER wherever possible, e.g., an attachment to a backhoe is preferred to having a jackhammer manually held.

8. LIGHTING

GENERAL

It has been reported (90) (142) that a quarter of the human body's caloric energy is used for the process of seeing, when vision is normal and illumination is sufficient. Under less than optimal conditions, more is used, and the oculomotor system has to rob other bodily functions to keep the eyes functioning and prevent fatigue from setting in. One result under such conditions is slower reactions with greater susceptibility to errors and accidents.

In the construction trades the degree of illumination is often taken for granted, with little concern for "proper" lighting levels. Oftentimes, construction sites are lit with a series of randomly located strings of incandescent bulbs or spotlights. It is acknowledged that perhaps the lighting levels need not be as stringent or demanding as those required in close, precise work such as circuit board technology or watch repair; however, by the nature of the job, construction workers are often required to work outside during the "dark hours", underground in tunnels or concrete pipes, and in other unlighted spaces such as attics and crawlspaces. At least some degree of adequate lighting is required in order to accomplish the job. As in the previous sections of this report, lighting as an environmental factor greatly affects worker health, productivity, and safety.

By providing more attention to worksite lighting by all concerned, a job can be accomplished faster, better, less expensively in the long run, and safer for the construction industry's most valuable asset- the construction worker.

Lighting in the construction industry is another topic for which practically no research has been published. The majority of the information available concerns itself with interior industrial work or architectural and special effects lighting. The information which follows is not presented in-depth and does little justice to such an important topic. Rather, it is presented to identify a very real problem, that is, the effect of lighting on construction productivity, so that those concerned may be cognizant of its impact for planning and estimating purposes.

EFFECTS

Light is measured in "footcandles." One footcandle (fc) is equivalent to the amount of light perceived from a standard candle one foot away. Because light spreads out in all directions from its source, at two feet away only ¼ footcandle would be perceived from that same candle.

A "foot lambert" is a level of brightness of an object and includes reflected light. For example, if there are 25 footcandles of light available and paper reflects 80% of the light, the paper reflects 20 of the 25 footcandles or 20 foot lamberts.

Proper illumination levels are important since visual efficiency (acuity and color discrimination) usually improves (up to a limit) with increasing levels of illumination (145) (32)(99)(136). However, extreme levels of illumination may impair performance due to glare (6)(145) which lessens visual contrast and legibility (35)(104)(145)(11). Considerations should be given to minimizing glare, extreme contrasts, shadows, and flickering light sources.

Glare, which is excessive light falling on the retina, lessens visibility by decreasing contrast between the item of work and the background environment (11)(145). Contrast refers to the difference in brightness between the work item and the environmental brightness. Too little or too great a contrast adversely affects visibility. Shadows, too, obscure the actual shapes of items within the working area, while flickering, usually caused by faulty light sources, is distracting and induces disorientation.

Light not only operates man's sense of sight but his objective orientation as well, thus insuring his immediate safety. In addition, light regulates the various nerve pulsations originating in the retina and elsewhere which influence and regulate other physiologic systems within the body and consequently, long term health. In this manner, light indirectly affects muscular tension (89)(90)(92), heart rate (90)(91), blood chemistry (90)(126), glandular secretions (18)(39)(90)(110)(122)(126) and toxin buildup (59)(90).

Logan (90) gives the example (91) where:

> adequate light of suitable color composition dilates the blood vessels and increases peripheral circulation, thus promoting insensible perspiration which rids the body of toxins and lightens the load on the kidneys. Kidney degeneration is a factor in various terminal diseases.

Working under sufficient light conditions results in more efficient physiologic action. Logan (90) states:

> Less energy must be expended internally to meet the demands made on the body by its external environment. The optimum balance between the body's internal economy and the pressure of its environment (homeostasis) is more easily achieved. There is a lower caloric need to fuel the oculomotor system, and a slower fatigue toxin buildup.

Light also affects mental efficiency : 2.4 times more light is required to permit an understanding of what one is seeing than to just detect its presence (90).

Figure 44 graphically depicts the range of natural illumination levels on earth. Light is reflected, transmitted or absorbed by matter. In twilight, to the human eye, objects lose their detail and colors. Figure 45 illustrates the cross-section of the retina. In daylight, the fovea is the most sensitive part of the retina, but is blind in the dark. There is also a permanent blind spot on the nose side of the retina where the nerve fibers from the retina pass through a hole to the brain. Under darkened conditions the most sensitive part of the retina is 20° from the fovea away from the nose (113)(124). The rods, which are sensitive to dim light, do not distinguish between different

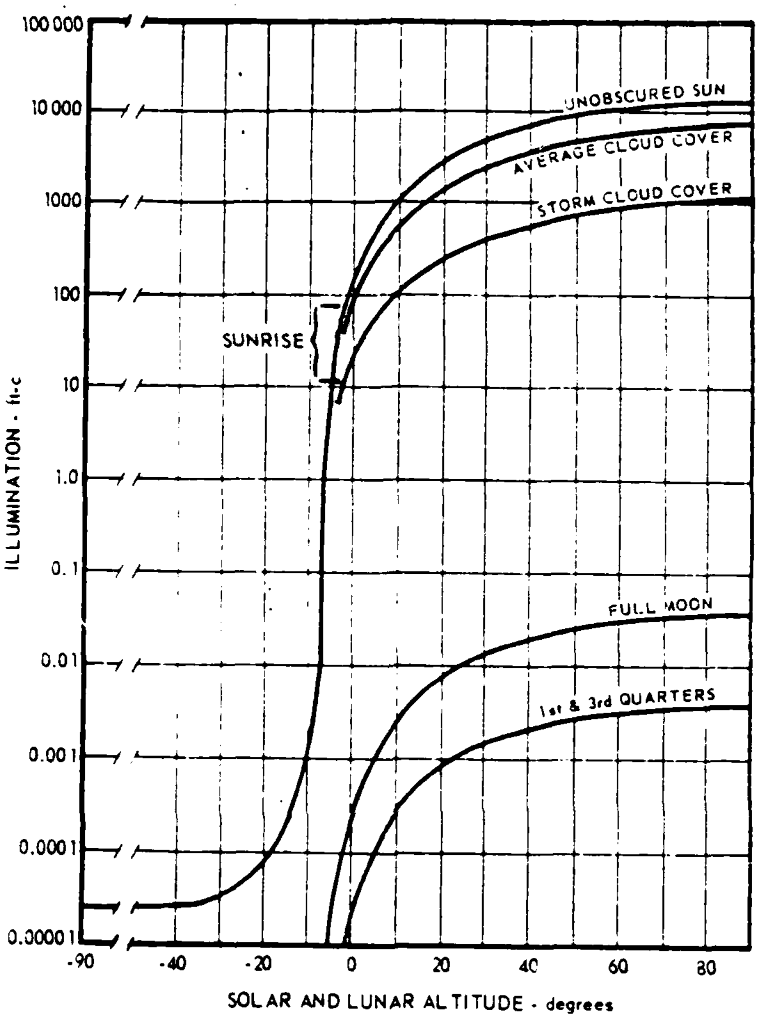


FIGURE 44

Range of Natural Illumination On Earth From The Sun and the Moon. Values increase from minimum before sun or moon-rise to maximum at the zenith (150).

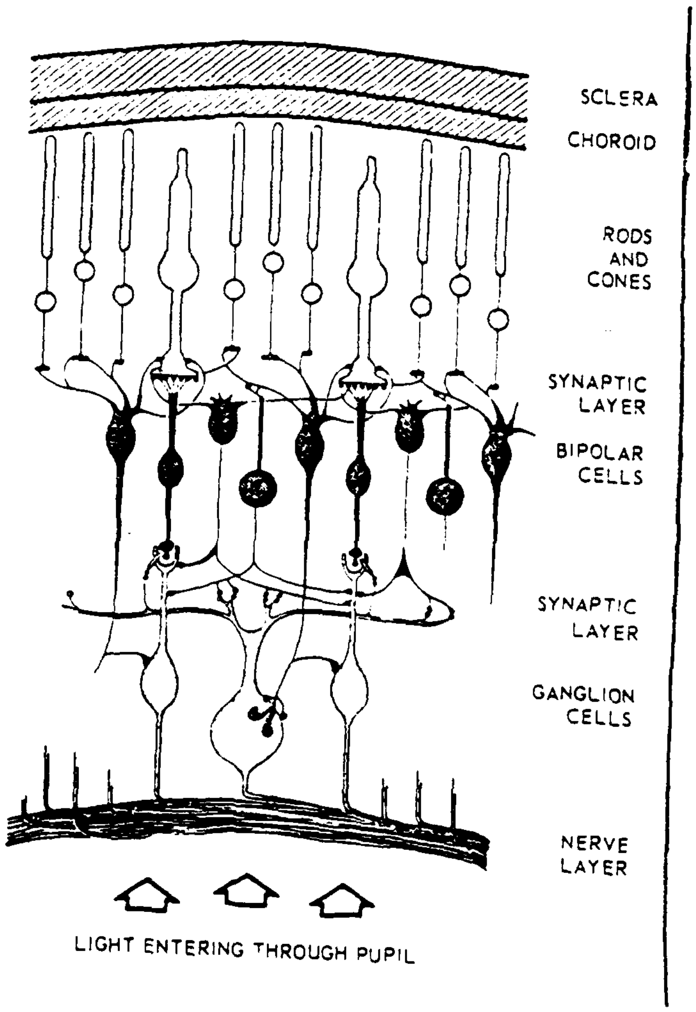


FIGURE 45

Plan of the Retina. The rodless area is the fovea (150).

color lights and take on a greyish silhouett capability. Green objects generally look brighter than other colored objects because the rods are most sensitive to green light while red objects appear black due to the rods' insensitivity to red light. Consequently, shadows may be difficult to distinguish from something red because both appear dark (124). In order to perform properly, workers must be able to distinguish between objects sufficiently, and this can be accomplished through the provision of adequate lighting.

Table 11 shows the effects of the quality of illumination on performance of visual tasks. The required brightness is given in foot lamberts (fL) and if special reflectance is required, say 90%, 50%, or 10%, then the required illumination will be greater, as shown in the equation (98):

$$\text{required illumination}(f_c) = \frac{\text{required luminance (fL)}}{\text{reflectance}}$$

In contrast to a darkened situation, levels of illumination that are too high can actually hinder performance by minimizing the perceived differences in the features of the objects worked on, such as reducing shadows which characterize certain patterns. Thus, more footcandles can be worse than not enough.

Table 12 illustrates the effect that changes in illumination can have in an industrial setting. Much of the work listed is not unlike that performed by construction trades as far as degree of manual performance is concerned. Construction management should heed the example as an

Category of seeing task	Guide brightness, fL	Footcandles for specified reflectance conditions 90%	50%	10%
A. Easy	Below 18	Below 20	Below 36	Below 180
B. Ordinary	18-42	20-45	36-84	180-420
C. Difficult	42-120	45-133	84-240	420-1200
D. Very difficult	120-420	133-455	240-840	1200-4200
E. Most difficult	420 up	455	840	4200

TABLE 11

Categories of Difficulty of Seeing Tasks With Brightness and With Footcandles for Specified Reflectance Conditions (98).

Type of work activity	Illumination, fc Original	New	Change in work output, %	Source
Metal-bearing manufacturing	4.6	12.7	15	Luckiesh and Moss [26]
Steel machining	3.0	11.5	10	Luckiesh and Moss [26]
Carburetor assembly	2.1	12.3	12	Luckiesh and Moss [26]
Iron manufacturing	0.7	13.5	12	Luckiesh and Moss [26]
Buffing shell sockets	3.8	11.4	9	Luckiesh and Moss [26]
Letter sorting	3.6	8.0	4	Luckiesh and Moss [26]
Piston-ring manufacturing	1.2	6.5	13.0	Magee, as described by Luckiesh [22]
	1.2	9.0	17.9	
	1.2	14.0	25.8	
Inspecting roller bearings	2.0	6.0	4	Hess and Harrison [16]
	2.0	13.0	8	
	2.0	20.0	12.5	
Iron-pulley finishing	0.2	4.8	35	Viteles [38, p. 301]
Spinning	1.5	9.0	17	Viteles [38, p. 301]
Weaving worsted cloth	13.3	29.0	5.3	Weston [39]
Spinning wool yarn	11	42	9.6	[44]
Weaving automobile cloth	14-17	32	4.7	[44]
Card punching	28	49	6.7	[43]
Mail handling (Richmond Post Office)	10	45-50	8.0	[40]

TABLE 12

Results Of Surveys Showing the Change In Work Output Following Improvement of Illumination of Work Areas (98).

opportunity for improvement in their own organization.

Some construction tradesmen, such as welders, face unique situations. Welders must protect their eyes from ultra-violet, visible, and infrared light by wearing goggles which transmit 1/250th to 1/50,000th of the incident light (44). The problem exists where if the goggles are used in ordinary light, the welder is prevented from seeing anything at all when the arc is extinguished. An experienced welder in daylight may nevertheless be able to determine the weld-points; however, an inexperienced one would be tempted to weld with lifted goggles. Not only is this a safety hazard, but continuous shifting of the goggles is inefficient, interferes with the work, and increases the potential for errors.

The luminance of the center of a welding arc is about 1% that of the sun (44) but use of the goggles allows the welder to work without discomfort. The fumes and smoke assist in scattering light and thus, aid in the illumination. Every time the welding stops, however, the welder is forced to remove the goggles in order to see and consequently, the eyes have to readjust with each change from dark to light and light to dark. Thus, the number of adjustments with the goggles should be minimized to the greatest extent possible.

Many workers fail to make the obvious connection between light and accidents. The immediate effect of light is related to accidents and in the long run, to health by what psychologists call the "anticipatory timing of behavior"

(1)(89). With good light and sight, timing is properly anticipated and accidents are less frequent. Additionally, the continual effort of the body to establish equilibrium with the extermal world when interfered by improper lighting, leads to fatigue, to mistakes, and to accidents (89). It has already been shown how insufficient lighting makes it difficult to distinguish shadows, colors, and shapes. McCormick (98) demonstrated that proper selection of illumination levels in an industrial setting can lead to a 43% reduction in the accident rate. Other investigators have directly linked illumination factors as a direct cause of accidents of varying severity (9)(78)(115)(133)(145). Additional accidents are likely to occur through personal negligence, as in the case of a welder working without goggles.

RECOMMENDATIONS

There is generally no acceptable excuse for working under inadequate lighting conditions. With modern technical advances in portable battery devices and "quiet" generators, it is either through negligence, apathy, or financial shortsightedness that workers are required to perform under such situations.However, as lighting affects health, safety, degree of error, timing and accuracy, management should take an active interest in providing optimum conditions. The following recommendations are made:

(1) PROVIDE LIGHTING OF ADEQUATE INTENSITY, capable of being oriented IN ANY DIRECTION, situated to

MINIMIZE SHADOWS AND EXTREME CONTRASTS, SCREENED to prevent glare, and of a quality to MINIMIZE FLICKERING. Both quantity and quality should be considered (145).

(2) In determining lighting adequacy USE ILLUMINATION STANDARDS such as the American National Standards Institute guidelines (ANSI 1965,1970), the British Illuminating Engineering Society Standards or the International Occupational Safety And Health Information Center Standards of the International Labor Office, Geneva, Switzerland.

(3) Glare may be minimized by USING SEVERAL LOW INTENSITY SOURCES RATHER THAN ONE HIGH ONE.

(4) Shadows can be minimized by USING LIGHT COLORS TO CONTRAST AGAINST A DARKER BACKGROUND.

(5) Allow workers ADEQUATE TIME (5 to 40 minutes) FOR THEIR EYES TO ADAPT to a dark environment after coming in from the "light" (145). Inadequate adaption invites an unsafe condition. Adaption from dark to light can be effected much faster, from a few seconds to several minutes (114)(145).

(6) In the case of welding, Fortuin and Frant (44) suggest switching on a STRONG BEAM OF LIGHT (say, 1 kw iodine lamp) after the goggles are in place to illuminate the work piece sufficiently for its main features to be discernible. Once the arc has formed, such added lighting is not needed as the smoke will diffuse the light evenly and neighboring areas can be seen with the goggles in place.

(7) For workshops and certain construction areas,

GOOD WALL, FLOOR AND CEILING REFLECTANCE would be helpful. Special paints are available which have a high coefficient of reflection for visible light and (for welding) a low one for ultraviolet radiation. The greater the reflection, the less will probably be the requirement for additional artificial lighting.

9. CONCLUSION

From the information presented in the previous sections of this report, one might now feel as though there is a perfect situation for construction projects under all seven environmental conditions discussed. This "perfect" working environment would probably involve a project at sea level elevation (altitude) in the vicinity of a waterfall or a crashing surf (ionization). The temperature would be maintained at 75°F (temperature), with an accompanying humidity of 60% (humidity) and a steady 15 mph breeze. Although the majority of the work would be performed during the day, some shiftwork is involved, manned by capable volunteers. For the most part, the shifts are permanently assigned but where rotating is inevitable, workers are rotated no sooner than once per month (shiftwork). Because the contractor uses modern, silent equipment, rarely does the noise level get much above 60 hz, the noise level above which conversation becomes appreciably impaired (noise). The tools and equipment used are highly insulated and padded so that the inevitable vibrations are practically totally absorbed before reaching the man-equipment interface (vibrations). The majority of the work is performed in healthy sunlight, but where artificial lighting is required, the degree of illumination is right for the task as well as for the background environment, and lighting is angled in such a way that both glare and shadows are eliminated (lighting).

In reality, life is not such a panacea. Instead, jobs are accepted where and as they become available under whatever conditions may exist. Equipment, tools and manpower depend on availability, cost, and ability to perform the work, regardless of the means or consequences. For these reasons, it is most likely that one or many of the adverse situations discussed in this report exist now on any construction project and will exist on future ones. Some of the adverse conditions are dependent on either "The Almighty" or nature and cannot be prevented by man. Others are totally within his capability. In either case, they can be minimized even though it may be at some cost.

Management, when planning and estimating projects, should definitely compare the short term costs of taking preventive action against the long term costs of accidents, injuries, excessive waste and rework. Added to these should be the hidden costs of insurance premiums, reputation, loyalty of workers, and goodwill. A contractor cannot afford to ignore environmental factors as they affect worker productivity.

As a means of summarization, following is a very brief guide to assist management in determining the costs of taking preventive action against adverse environmental conditions. The list is not all-inclusive and does not include environmental factors not previously discussed in this report (such as effects of dust or compression on human productivity) nor combined effects (such as the combination of cold and altitude or noise and shiftwork). These are recommended as topics for future research.

As a minimum, it is suggested that the contractor and/or planner/estimator consider the following applicable factors in the cost estimate for project costs:

CONSIDERATIONS IN RESPONSE TO ADVERSE WORK ENVIRONMENT	POTENTIAL SAVINGS OF FOLLOWING RECOMMENDATIONS
ALTITUDE	**ALTITUDE**
-Physical examinations -Altitude/hypoxia training -Hire acclimatized workers (higher wages) -Gradual acclimatization of workforce -Gradual ascension/descension to and from the high altitude -Rental costs for housing workers at high altitude -Per diem costs for housing workers at high altitude -Slower work response time -Additional heavy equipment -Home office/worksite communication expense -Transportation costs for preconstructed materials (prefabricated work) -Emergency oxygen supply -Increased rework (10%)	-less waste -less rework -less labor costs -daily transportation costs -workman's comp/insurance premiums -absenteeism
CONTROLLED IONIZATION	**CONTROLLED IONIZATION**
-Dust and static electricity control -Spray/shower rental	-less inefficiency -less waste -less rework

CONSIDERATIONS IN RESPONSE TO ADVERSE WORK ENVIRONMENT	POTENTIAL SAVINGS OF FOLLOWING RECOMMENDATIONS
-Static-free materials	-morale, motivation
-Hauling costs in lieu of open burning	-medical, workman's comp, insurance
-Shielded equipment	-absenteeism
TEMPERATURE & HUMIDITY	**TEMPERATURE & HUMIDITY**
-Physical examinations	-less inefficiency
-Temperature/humidity training	-less waste
-Hire acclimatized workers (higher wages)	-less rework
-Gradual acclimatization of workforce	-less labor costs
-Slower work response time	-medical, workman's comp, insurance
-Adjust rate of work/ rest periods	-absenteeism
-Financial incentives/benefits	-morale, motivation
-Employment of temporary workers	
-Warning signs and "buddy system"	
-Foul weather gear (cold)	
-Increased rework	
SHIFTWORK	**SHIFTWORK**
-Physical examinations	-better productivity
-Shift rotation training	-less waste
-Financial incentives/ benefits	-less rework
	-less labor costs
	-medical, workman's comp insurance
	-absenteeism
	-morale, motivation
NOISE	**NOISE**
-Equipment costs for low noise emitting equipment	-morale, motivation
-Barrier construction	-less waste
-Labor costs in rotating workers more frequently	-less rework
-Noise protection training	-medical, workman's comp, insurance
-Hearing protection apparatus	-absenteeism
-Background music	
-Initial & annual audiograms	
-Interior acoustical treatment	

CONSIDERATION IN RESPONSE TO ADVERSE WORK ENVIRONMENT	POTENTIAL SAVINGS OF FOLLOWING RECOMMENDATIONS
VIBRATION	VIBRATION
-Equipment costs for minimal vibration/oscillation equipment -Equipment and haul road preventitive maintenance -Labor costs in rotating vibratory tool operators -Equipment costs in lieu of manpower	-major equipment repair costs -labor costs -medical, workman's comp, insurance -absenteeism
LIGHTING	LIGHTING
-Lighting of sufficient quantity and quality -Labor time to allow for proper light adaption -High intensity light (welding) -Reflectance treatment of shop areas	-less waste -less rework -worker efficiency -utility bills (lower with reflectance treatm't) -morale,motivation -medical, workman's comp, insurance -absenteeism

APPENDIX A

Table 1 Environments just severe enough to produce a reliable deterioration in performance

Environmental condition	Condition just severe enough to produce a reliable deterioration in performance	Task	Kind of deterioration in performance	Probable reason for deterioration	References
Heat	Air temperature 27°C (80°F)	Making knitted clothes	Reduced output	Discomfort	Link and Pepler, 1970*
		Reading	Reduced speed and comprehension		Wyon, 1970
		Making munitions	Increased accidents		Osborne, Vernon and Muscio, 1922*
		Coal mining	Increased accidents		Vernon, Bedford and Warner, 1928*
Cold	Air temperature · 13°C (55°F)	Tracking	Reduced time on target	Cold hands are clumsy	Teichner and Wehrkamp, 1954 Teichner and Kobrick, 1955
		Making munitions	Increased accidents		Osborne, Vernon and Muscio, 1922*
Dim light	7 to 10 Footcandles	Reading 7-point newspaper type	Reduced speed	Small details are not sufficiently visible	Tinker, 1943
		Reading 6-point italic type			Tinker, 1952
Glare	(Depends upon the angle of the glare source to the line of sight, as well as upon its brightness)	Inspecting cartridge cases	Reduced speed	Masking by the light which scatters within the eye	Wyatt and Langdon, 1932
		Typesetting by hand			Weston, 1949 (page 191) †
Noise – Continuous	100 decibels	Tapping 1 of 5 targets in response to 1 of 5 lights	Increased errors	Distraction by noise	Broadbent, 1953, 1957; Wilkinson, 1963
		Threading photographic film through machine in dim light	Increased broken rolls and shutdowns attributed to the man		Broadbent and Little, 1960
Noise – Intermittent	95 decibels for 1 second	Reporting differences between pairs of cards	More omitted reports	Distraction by noise	Woodhead, 1959
	Noise varying randomly between 90 and 65 decibels	Recoding digits	Increased variability in rate of work		Sanders, 1961
Noise – Interference with speech communication	70 decibels from 600 to 4 800 Hertz	Speaking at 3 feet	Reduced comprehension	Masking of the speech by the noise	Beranek, 1947*
		Telephoning			Morgan, Cook, Chapanis and Lund, 1963 †
Vibration of man	0·02 inch at 19 Hertz.	Reading 12-point digits at 10 feet with 0·2 foot Lamberts of illumination	Increased errors and reduced speed	Rotary vibration of the head at its resonant frequency of about 20 Hertz blurs the images on the retina of the eye	Dennis, 1965
Motion of man	Up to 0·3G at 0·3 Hertz, (raft on waves)	Adding columns of numbers	Fewer correct additions	Motion sickness	Brand, Colquhoun, Gould and Perry, 1967
Acceleration	3G upward (gravitational force 3 times the normal size)	Subtracting 3s starting with a number close to 100	Reduced speed	Reduced supply of oxygen to the brain	Frankenhaeuser, 1958
Weightlessness	1/6 G, (gravitational force one sixth the normal size, as on the moon)	Tightening bolts	Reduced speed	Reduced postural stability	Shavelson and Seminara, 1968
		Joining connectors Threading nuts			
Decompression	0·7 atmospheres absolute, or 5 000 feet above sea level	Judging the orientation of a mannikin while cycling at a moderate speed	Longer reaction time	Reduced supply of oxygen to the brain	Denison, Ledwith and Poulton, 1966

Environmental condition	Condition just severe enough to produce a reliable deterioration in performance	Task	Kind of deterioration in performance	Probable reason for deterioration	References
Compression	2 atmospheres absolute	Sorting cards	Increased number of delayed responses	Nitrogen narcosis	Poulton, Catton and Carpenter, 1964
Carbon monoxide	Carboxyhaemoglobin 8% in non-smokers	Adding columns of numbers	Reduced speed	Reduced supply of oxygen to the brain	Lawther, 1971
Alcohol	Blood alcohol 20 milligrams per 100 millilitres, (30 minutes after drinking 1 glass of sherry)	Reporting changes in 8 figure numbers while driving in traffic	More omitted reports	Depressed brain function	Brown, 1970
Hangover from sleeping tablets	A double dose of sleeping tablets taken 10 hours previously (200 milligrams of quinalbarbitone sodium)	Tracking simultaneously on 4 instruments	Reduced time on target	Depressed brain function	McKenzie and Elliott, 1965 Hartman and McKenzie, 1966
Loss of sleep	Sleep debt of 5 hours. (Loss of 5 hours sleep on 1 night, or of 2·5 hours on each of 2 consecutive nights)	Listening to 0·5 second tones presented every 2 seconds for occasional shorter tones	More signals missed	Occasional lapses of alertness	Wilkinson, 1969
Mental work overload	Having to look at, or attend to, 2 things simultaneously	Tracking while pressing 1 of 5 keys in response to 1 of 5 lights	Increased tracking error	Not being able to look in 2 directions at once	Garvey, 1960
		Watching moving dial pointers while listening to messages	Increased errors on messages	Not being able to attend to 2 things at once	Poulton, 1958
Temporary exhaustion	Stepping up 1 foot and down again 200 times in 7 minutes	Difficult tracking	Increased time to perform task	Insufficient supply of oxygen to the brain	Hammerton and Tickner, 1968
	Squeezing stiff spring 25 times in 25 seconds with thumb	Difficult tracking using the same thumb muscles	Increased time to perform task	Insufficient supply of oxygen to the thumb muscles	Hammerton and Tickner, 1969a
Constant attention to detail (vigilance)	20 minutes duration	Watching clock hand (a) jumping every second, for occasional barely detectable double jumps, and (b) moving continuously, for occasional 0·2 sec. stops.	More signals missed	Occasional failures to look, coupled with greater caution in reporting signals	Mackworth, 1968
Work after isolation in the dark	24 hours of isolation	Solving a difficult problem	Problem less often solved	The man becomes too highly aroused by the task	Suedfeld, Glucksberg and Vernon, 1967
		Thinking of uses for objects	Fewer uses thought of		Suedfeld and Landon, 1970
Danger producing fear	Threat of injury — before emergency landing	Following complicated instructions Remembering instructions	Increased errors	The man is too highly aroused	Berkum, Bialek, Kern and Yagi, 1962
	before first parachute jump	Difficult tracking tasks	Increased time to perform task		Hammerton and Tickner, 1969b

*Evidence from fitted functions, not from direct statistical tests
† Original evidence not seen

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APPENDIX B

UNITS AND CONVERSIONS

ALBEDO:
The per cent of diffused reflection of "white light" for a given surface. (See 17-2).

AMU (amu):
Atomic mass unit (defined as: 16 amu = the atomic mass of the most abundant isotope of oxygen).

ATMOSPHERE (atm):
The pressure exerted by 76 cm mercury with a density of 13.5951 gm/cm^3 at 1 g (the standard barometric pressure at sea level).

1 atm = 1.01325 × 10^6 dynes/cm^2
= 1033.2 gm/cm^2
= 760 mm Hg
= 14.696 psi

BRITISH THERMAL UNIT (Btu):

1 Btu = 1.0550 × 10^{10} ergs
= 251.995 gm-cal
= 778.77 ft-lbs
= 0.25199 kcal
1 Btu/hr = 0.1667 Btu/min
= 0.04199 kcal/min
= 0.2932 watt
1 Btu/min = 0.25199 kcal/min
= 0.02359 hp
= 17.595 watts
1 Btu/ft^2, hr = 2.7125 kcal/m^2, hr

BTPS:
Body Temperature (=37° C), ambient Pressure, and Saturated (water vapor pressure = 47 mm Hg). (See 15-15)

CALORIC EQUIVALENT OF OXYGEN:
One liter of oxygen (STPD) consumed is equivalent to 4.825 kcal of metabolic heat produced, when the R.Q. is 0.82.

CANDLE (c):
The unit of luminous intensity. (See 17-1).
1 candle = 1 lumen/steradian

CENTIMETER (cm):

1 cm = 0.03280 ft
= 0.3937 in
= 0.01 m
= 10 mm
= 1 × 10^4 μ

(See also Square Centimeter, Cubic Centimeter).

CENTIMETER-CANDLE (phot):
1 phot = 1 × 10^4 lux

CENTIMETERS PER SECOND PER SECOND:
1 cm/sec^2 = 0.0328 ft/sec^2

CENTIPOISE:
Unit of absolute viscosity
1 centipoise = 0.01 poise

CLO (clo):
The unit of insulation resistance for clothing
1 clo = 0.18 °C m^{2}hr/kcal
= 0.88 °F ft^{2}hr/Btu

CUBIC CENTIMETER (cc or cm^3):

1 cc = 3.531 × 10^{-5} ft^3
= 0.061023 in^3
= 1 × 10^{-6} m^3
= 1000 mm^3
= 2.6417 × 10^{-4} gal (US fluid)
= 0.0338 oz (US fluid)
= 2.113 × 10^{-3} pint (US liquid)
1 cc/sec = 0.0021186 ft^3/min

CUBIC FOOT:

1 ft^3 = 1728 in^3
= 28.32 liters
= 0.02832 m^3
1 ft^3/min = 472.0 cc/sec
= 0.4720 liter/sec
= 62.43 lbs H_2O/min
1 ft^3/sec = 1699.3 liters/min

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CUBIC INCH:

1 in^3 = 5.787 × 10^{-4} ft^3
= 1.639 × 10^{-2} liter
= 1.639 × 10^{-5} m^3

CUBIC METER:

1 m^3 = 35.3144 ft^3
= 6.1023 × 10^4 in^3
= 999.973 liters

DECIBEL (db):
Used for comparing power levels, acoustical or electrical.

1 db = 10 $\log_{10}$ P/P_0 where P is the power to be compared to a reference power P_0
1 bel = increase in power (P) by a factor of 10

(See also Sound Pressure Level).

DEGREE (angular):

1 deg = 60 minutes
= 0.01745 radian
= 3600 seconds
1 deg^2 = 3.0462 × 10^{-2} steradian

DEGREES CENTIGRADE (°C):
°C = 5/9 (°F - 32)
1 °C = 1.8 °F

DEGREES FAHRENHEIT (°F):
°F = (9/5 × °C) + 32
1 °F = 0.556 °C

DEGREES PER SECOND:
1 deg/sec = 0.017453 radian/sec
= 0.1667 rpm

DYNE:
1 dyne = 1.0197 × 10^{-6} kg
= 2.2481 × 10^{-6} lb
1 dyne-cm = 1 erg

DYNE-SECOND PER SQUARE CENTIMETER:
Unit of viscosity. (See Poise).

DYNE PER SQUARE CENTIMETER:
1 dyne/cm^2 = [illegible] × 10^{-7} atm
= 0.0010197 gm/cm^2
= 4.0148 × 10^{-4} in H_2O
= 7.500[illegible] × 10^{-4} mm Hg
= 1.450[illegible] × 10^{-5} psi

ELECTRON CHARGE (e):
e = 1.602 × 10^{-19} coulomb

ERG:
1 erg = 9.4805 × 10^{-11} Btu
= 7.3756 × 10^{-8} ft-lb
= 2.3889 × 10^{-11} kcal
= 8.8510 × 10^{-7} lb-in

FOOT (ft):
1 ft = 30.48 cm
= 12 in
= 0.3048 m
(See also Square Foot, Cubic Foot).

FOOT-CANDLE (ft-c):
1 ft-c = 1 lumen/ft^2
= 10.764 lumen/m^2

FOOT-LAMBERT (ft-L):
1 ft-L = 1.0764 millilamberts

FOOT PER MINUTE:
1 ft/min = 0.3048 m/min
= 0.005080 m/sec
= 0.011364 mph

FOOT PER SECOND:
1 ft/sec = 1.0973 km/hr
= 0.5921 knot (per hr)
= 0.6818 mph

FOOT-POUND (ft-lb):
1 ft-lb = 0.001285 Btu
= 1.3558 × 10^{7} ergs
= 3.2389 × 10^{-4} kcal
1 ft-lb/min = 3.0303 × 10^{-5} hp
= 0.01667 ft-lb/sec
= 0.022597 watt
1 ft-lb/sec = 0.001818 hp
= 0.01943 kcal/min
= 1.3558 watts

G (g):
The acceleration of gravity (also the acceleration of a vehicle).
1 g = 32.174 ft/sec^2
= 980.665 cm/sec^2

G (G):
The unit of force causing displacement of organs and fluids in the body when the body is accelerated, where 1 G = force per unit mass due to acceleration of 1 g (See G-[illegible]).

GRAM (gm):
1 gm = 0.001 kg
= 1000 mg
= 0.03527 oz
= 0.0022046 lb
1 gm/cm^3 = 62.428 lbs/ft^3
1 gm/hr = [illegible] lb/day
= 0.0000367 lb/min
gm/liter = [illegible]2427 [illegible]
1 gm/cm^2 = [illegible] × 10^{-4} atm
= [illegible] dynes/cm^2
= 0.7356 mm Hg
= 0.014223 psi
1 gm/m^2, hr = 2.73 × 10^{-5} gm/cm^2, sec
= 0.7448 lb/ft^2, hr

GRAM-CALORIE (gm-cal):

1 gm-cal = 3.0874 ft-lbs
= 0.001 kcal

HEMATOCRIT:
The height of the column of red blood cells in a tube of whole blood which has settled or has been centrifuged to separate cells from plasma. Usually expressed in per cent.

HORSEPOWER (hp):
1 hp = 3.300 × 10^{4} ft-lbs/min
= 550 ft-lbs/sec
= 10.688 kcal/min
= 745.7 watts

INCH (in):
1 in = 2.540 cm
= 0.0833 ft
= 25.40 mm
(See also Cubic Inch, Square Inch)

INCH OF WATER (in H_2O):
1 in H_2O = 0.002458 atm
(at 4°C) = 2490.82 dynes/cm^2
= 0.0361 psi
= 1.868 mm Hg

JOULE:
1 joule = 1 watt-sec

KILOGRAM (kg):
1 kg = 1000 gm
= 2.205 lb
= 32.1507 oz

UNITS AND CONVERSIONS

KILOGRAM-CALORIE (kcal or large Calorie):
1 kcal = 3.9683 Btu
= 4.186×10^{10} ergs
= 1000 gm-cal
= 3087 ft-lbs
1 kcal/hr = 0.0661 Btu/min
= 0.857 ft-lbs/sec
= 0.1667 kcal/min
= 1.161 watts
1 kcal/m^2 hr = 0.3687 Btu/ft^2 hr
1 kcal/min = 3.9685 Btu/min
= 51.457 ft-lbs/sec
= 0.093557 hp
= 69.767 watts

KILOGRAM-CENTIMETER SQUARED:
1 kg-cm^2 = 0.3417 lb-in^2

KILOGRAM-METER PER SECOND:
[illegible]
[illegible] watts

KILOMETERS PER HOUR:
1 km/hr = 0.911 ft/sec
= 0.5396 knot
= 0.6214 mph

KNOT (nautical mile):
1 knot = 1.689 ft/sec
= 1.853 km/hr
= 1.1516 mph

LAMBERT (L):
Unit of surface brightness. (See 17-1).
1 L = 0.3183 c/cm^2
= 2.0536 c/in^2
= 1 lumen/cm^2

LITER (l):
1 liter = 0.03531 ft^3
= 61.02 in^3
= 1000 ml
1 liter/min = 5.886×10^{-4} ft^3/sec
1 liter/sec = 2.12 ft^3/min

LUMEN:
1 lumen = 0.001496 watt
= 0.07958 spherical candle power
1 lumen/ft^2 = 1 ft-c
= 10.764 lumen/m^2

LUX:
(See Meter-Candle)

METER (m):
1 m = 100 cm
= 3.281 ft
= 39.37 in
(See also Cubic Meter).

METER-CANDLE (lux):
1 lux = 1 lumen/m^2
= 0.092903 ft-c

METER PER SECOND:
1 m/sec = 3.281 ft/sec
= 3.600 km/hr
= 2.2369 mph

MICRON (μ or mu):
1μ = 10^{-6} meter
= 3.937×10^{-5} in
= 0.001 mm

MIL:
1 mil = 0.001 in
= 0.0254 mm
= 25.40μ

MILES PER HOUR (mph):
1 mph = 88 ft/min
= 1.4667 ft/sec
= 1.6093 km/hr
= 0.8684 knot

MILLIGRAM (mg):
1 mg = 0.001 gm
= 3.5274 oz
= 2.2046×10^{-6} lb
1 mg/m^3 = 6.243×10^{-4} lb/ft^3

MILLILAMBERT (mL):
1 mL = 0.929 lumen/ft^2
(perfectly diffused light)

MILLILITER (ml):
1 ml = 1.000028 cc
= 0.061025 in^3
= 0.001 liter
= 0.0338 oz (US fluid)

MILLILITERS PER HOUR:
1 ml/hr = 0.06102 in^3/hr

MILLIMETER (mm):
1 mm = 0.10 cm
= 0.03937 in
= 1000μ
(See also Square Millimeter).

MILLIMETER OF MERCURY (mm Hg):
1 mm Hg = 0.0013158 atm
(at 0°C) = 1333.22 dyne/cm^2
= 1.3595 gm/cm^2
= 0.019337 psi
= 0.535 in H_2O

MILLIREM:
1 millirem = 10^{-3} rem
(roentgen equivalent man)
(See 3-6).

MILLISECONDS (msec):
1 msec = 0.001 sec

OUNCE (oz):
1 oz = 28.3495 gm
= 0.0625 lb

OXYGEN SATURATION:
The ratio of the volume of oxygen (at STP) in a given unit volume of blood, to the maximum volume of O_2 that can be absorbed by that unit volume of blood at high partial pressures of O_2 (e. g. 760 mm Hg); usually expressed in per cent.

PARTS PER MILLION (ppm):
1 ppm = 1.0 mg/liter of H_2O
= 8.345 lbs/million gallons

PHON:
1 phon unit = SPL of a 1000 cycle/sec tone (See 16-5).

PHOT:
(See Centimeter Candle).

POISE:
Unit of viscosity.
1 poise = 1 dyne/sec, cm^2
= 1 gm/cm, sec
= 0.067196 lb/ft, sec

POUND (lb):
1 lb = 453.5924 gm
= 0.45359 kg
= 16 oz
1 lb/day = 18.89 gm/hr
1 lb/hr = 0.7559 gm/min
= 10.886 kg/day

POUND-INCH:
1 lb-in = 1.1298×10^6 dyne/cm

POUND-INCH SQUARED:
Unit of moment of inertia.
1 lb-in^2 = 2.9264 kg-cm^2

POUND OF WATER PER MINUTE:
1 lb H_2O/min = 0.01603 ft^3/min
= 2.670×10^{-4}/ft^3/sec

POUND PER CUBIC FOOT:
1 lb/ft^3 = 0.01602 gm/cm^3

POUNDS PER SQUARE INCH (psi):
1 psi = 0.06805 atm
= 6.8947×10^4 dyne/cm^2
= 70.307 gm/cm^2
= 51.715 mm Hg
= 27.7 in H_2O

POUNDS PER SQUARE INCH ABSOLUTE (psia):
Absolute pressure, where 0 psia = vacuum

POUND WEIGHT:
1 lb wt = 4.4482×10^5 dynes
= 453.59 gm wt

RAD (rad):
Radiation absorbed dose. (See 8-6).

RADIAN (rad):
1 radian = $\frac{1}{2\pi}$ circumference or revolution (0.15915)
= 57.296 deg
1 radian/sec = 57.296 deg/sec
= 9.549 rpm
1 radian/sec^2 = 572.96 rpm^2

RBE:
Relative biological effectiveness (See 8-6).

RELATIVE HUMIDITY:
The ratio of the quantity of water vapor in an atmosphere to the quantity which would saturate at the existing temperature. Also the ratio of pressure of water vapor to saturation pressure at that temperature.

REM:
Roentgen equivalent man. (See 8-6).

RESPIRATORY QUOTIENT (R.Q.):
The ratio of the rate of production of carbon dioxide (volume at STP per unit time) to the rate of uptake of oxygen (volume at STP per unit time).

REVOLUTIONS PER MINUTE (rpm):
1 rpm = 6 deg/sec
= 0.10472 radian/sec
1 rpm^2 = 0.001745 radian/sec^2

ROENTGEN (r):
1 r = ionization by X or γ-rays producing 1 electrostatic unit of charge in 1 cm^3 of air (STP)
= 83.0 ergs/gm

ROOT MEAN SQUARE (rms):
Square root of the mean of the squares of a set of numbers.

SONE:
Related to phon logarithmically (See 16-4, 16-5)

SOUND PRESSURE LEVEL (SPL):
SPL is sound pressure related logarithmically to a reference level of pressure (P_0), which by convention is 0.0002 dynes/cm^2. The defining equation is:
SPL = 20 $\log_{10} P/P_0$ in decibels
(See 16-3 for nomogram to convert sound pressure to SPL).

SQUARE CENTIMETER:
1 cm^2 = 1.076×10^{-3} ft^2
= 0.1550 in^2
= 100 mm^2

SQUARE FOOT:
1 ft^2 = 929.0 cm^2
= 144 in^2

SQUARE INCH:

1 in^2 = 6.4516 cm^2
= 0.006944 ft^2
= 645.1626 mm^2

SQUARE MILLIMETER:

1 mm^2 = 0.01 cm^2
= 0.001550 in^2

STANDARD DEVIATION (S. D.)

The square root of the average of the squares of deviation from the mean. Also called root mean square deviation. Same as Standard Error.

STERADIAN:

$\frac{1}{4\pi}$ solid angle around a point.
1 steradian = 3282.8063 deg^2
= 0.07958 sphere

STPD (Standard Temperature and Pressure, Dry):
0° C, 760 mm Hg, water vapor pressure = 0
(See .0-1).

WATT:

1 watt = 1 joule/sec
= 1 X 10^7 erg/sec
= 0.7376 ft-lb/sec
0.001341 hp
= 0.01432 kcal/min

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