POTENTIAL TRAUMA IN THE WORK PLACE

DESIGN AND USAGE OF PERSONAL PROTECTION

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INTRODUCTION

The concept of personal protective equipment is, of course, as ancient as our early civilization. There are only few, if any, who are not familiar with the biblical story of David and Goliath in which the latter was equipped with "a helmet of brass upon his head, and he was clad with a coat of mail; and he had greaves of brass upon his legs..."[1]

Our history books describe the magnificent advancements in personal protection achieved by the Roman Legions as they were carving the vast Roman Empire. The personal armor developed for and used by the European kings and dukes in the struggles and battles on the continent are pieces of personal protection equipment creating a veneration even to this day. However, these were instruments of war; our present concern is with personal protective equipment used in an occupational battleground; we direct our efforts for the benefit of Americans who are at work to earn a living in order to sustain a life style which the fruits of their labor will permit them.

The OSHAct makes it mandatory for each employer to furnish to each employee a place of employment which is free from recognized hazards that are likely to cause death or serious injury. The requirements in the Act place a burden on employers and their safety professionals and industrial hygienists to take prompt steps to eliminate any hazards or at least reduce their intensity. As a result, they often find that there is a need to introduce extensive engineering revisions of manufacturing processes or methods while in many other situations the need is only for relatively simple changes in the work practice.

The approach to safety and health hazards through engineering solutions is generally more reliable and often more desirable than protection dependent on personal protective equipment or human behavior. Engineering solutions can, in many cases, help eliminate or reduce the cause of accidents; examples of this kind can be found in exhaust systems; in power presses equipped with integrated safeguarding features such as sensing devices, and in power transmission equipment installed and protected with machine guarding. But when such an approach is not practical, the use of personal protective equipment is not only mandatory but it often provides the only means of protection against the specific work hazard. Dielectric protective gloves used against high electrical potential hazards are perhaps some of the more vivid examples of personal protective equipment, that, when used properly, can effectively prevent a fatality or a serious injury by electrocution. Members of the "Wise Owl" club provide rather convincing evidence as to the wisdom of using eye protective devices against objects possessing kinetic energy.

CONSIDERATIONS FOR NEED

When it is determined that there is a need to provide personal protective equipment because a work hazard exists it is, in fact, a partial admission of defeat. In essence, it is a recognition that the hazardous situation itself can't be eliminated entirely. But it is also necessary to recognize that many engineering solutions can be applied. The flying particles off a grinder can be blocked by a transparent shield rather than to have the operator be totally dependent on eye and face protective equipment. Corrosive, fuming or toxic chemicals should, where possible, be confined to closed pipes and vessels, supplemented by effective exhaust ventilation, rather than to have the worker protection totally dependent on chemically-resistant protective clothing and respirators.

In our imperfect work environments it is recognized that the situation is seldom reached when it can be stated that personal protection is no longer necessary. The essential thing to keep in mind is that work safety derived from the usage of personal protective equipment is really the last line of defense. After everything possible has been done to enclose the process, to substitute material, to safeguard the press, and to rearrange the work schedule; only when it is recognized that nothing remains but to protect the worker should considerations be given to the kind and extent of personal protection required.

DESIGN CONSIDERATIONS

When we discuss personal protection in the work place we are addressing ourselves to the need to protect various body parts against hazards found in the work environment. The main effort must be placed on recognizing the source, type, and intensity of the hazard and the body part (or parts) which is most likely to sustain an occupational injury by the hazard when not adequately protected. However, even when such situations are well analyzed and fairly well understood, there emerges a critical need to establish the level of tolerance that various body parts can sustain when assaulted by hostile work hazards, without experiencing an injury or a fatality. This, then, becomes the basis for the design of personal protective devices. When we possess technical information about the tolerance of the human body to withstand an electric shock without a serious injury or damage to our natural faculties, we can initiate the design of the protective devices which will provide adequate protection against such an electrical hazard. As we find in so many cases which deal with the design requirements for personal protective equipment, the medical information on human tolerance to assaults by hostile work-place forces is simply not readily available. Yet, as it will be shown, it must become known through medical research lest we are willing to accept personal safety devices which do not provide real personal protection and remain safety devices in name only.

<u>Head Protection</u>: The present OSHA standards which pertain to head protection are based on the American National Standards Institute standards Z89.1-1969 and Z89.2-1971.[2,3] The existing ANSI standards have evolved from previous standards and do not represent the results of exhaustive research in industrial head protection.[4]

In terms of impact forces, the standards specify a requirement to attenuate an average force of 850 pounds when the imparted energy is 40 ft-lb. The energy is derived from a steel ball 3 3/4" in diameter and weighing 8 pounds dropped from a height of 5 feet onto the apex (crown) of the helmeted head form. The transmitted force is computed by the Brinell formula:

$$F = 2.2 \times H \times \frac{\pi D}{2} \times D \sqrt{(D - \quad D^2 - d^2)}$$

where:

F = transmitted force in pounds
H = average Brinell hardness number of impression bar
D = diameter of the impression ball in millimeters
d = diameter of the impression in millimeters

What was the basis for such requirements? The 8-pound steel ball was evidently chosen because of its availability in large ball bearings.[5] The choice of the 5-foot drop height appears to have been arbitrarily chosen, "as to give impact against which you reasonably expect a wearable piece of headgear to provide protection."[6] Such a requirement is obviously not related to simulation of occupational accidents and, therefore, it can hardly be considered as a sound basis for the design of devices for head protection against impacting forces. Certainly, there is no medical basis for such performance requirements.

By the application of human tolerance data, it should be possible to reduce the likelihood or severity of injuries from impact of objects against the human skull in typical occupational environments where hazards to the head exist. The human tolerance leads to the following general principles: (a) effective absorption of the impact energy by the deformation of the helmet structure and component, (b) use of energy absorbing material in the head protection gear to cushion and spread the impact, and (c) design of head protection gear to reduce sharp-body penetration.

The degree of human tolerance to head impact is not well established, although considerable work has been done in this area. Since head impact research can't be based on a direct approach involving human subjects, the human tolerance to impact can be investigated only under indirect methods or at subinjury levels with human volunteers. Also, live animals and human cadavers have been assaulted in numerous ways and the resulting damage inspected and analyzed. However, the studies are too few and the methods are of such limited value that the present knowledge of human tolerance to impact remains inconclusive.

It has been reported that the values for maximum allowable transmitted force through a helmet designed and fabricated to present standards have been the maximum allowable force to the cervical vertebrae.[6,7] However, published research demonstrating human tolerance to dynamic cervical compression is not available.

Studies of vertebral tolerance[8] show the average ultimate static compressive strength of the cervical vertebrae to be 830 pounds and that of the lumbar vertebrae to be 1,200 pounds for ages 20-59. Patrick[9] has stated an approximate dynamic tolerance of 2,000 pounds for the lumbar vertebrae. If this static/dynamic ratio is applied to the cervical vertebrae, we find that the cervical dynamic tolerance is in the order of 1,360 pounds. This, then, is the level of tolerance presently being considered in developing criteria suitable for the design of head protection against impact.

Hand Protection: What is quite amazing to find in this country is the lack of suitable safety standards for hand protection. The exception is the ANSI standard J-6.6-1971[10] which contains performance requirements and test methods for industrial gloves used against the hazards of high voltage. The J-6 gloves, possessing dielectric properties, provide effective protection when used conscientiously and this fact was demonstrated on numerous occasions. Considering the National Safety Council published data on part of body injured in work accidents[11,12] we find that injuries to fingers account for 16-17% of all injuries. Only injuries sustained by the trunk of the body were higher. Numerically speaking, we are recording 400,000 finger injuries every year in this country which account for 10% of the compensation costs.

In our present efforts to develop performance criteria for firefighters gloves, it is quite likely that some of the performance requirements and test methods will be applicable to industrial gloves. For example, an injury due to cold, like injury due to heat, is a function of both the temperature level and the duration of exposure. In this type of injury, the tissue is irreversibly damaged due to oxygen deprivation and/or actual freezing of individual cells. The available literature on injuries due to cold is quite limited - certainly it is less extensive than that for injuries due to elevated temperatures. The data used are chiefly those of Stoll[13] and Meryman.[14]

The length of time required for permanent damage at subfreezing temperatures has not been completely established. Stoll gives a tissue temperature of 32°F(0°C) as the point of instantaneous degradation. She also describes a threshold range of reversible injury as corresponding to the range of threshold pain (tissue temperature of 18°C) to severe pain (tissue temperature 10°C). As more data on human tolerance becomes available, the subsequent design of the hand protective devices becomes more functional and by far more effective in reducing injuries from cuts, punctures, thermal energy, penetration, electrical potential, liquid penetration and abrasion while allowing for the task-related properties of dexterity, grip, and tactility.

Eye Protection: When we refer to eye protection, we must consider the fact that the human eye is one of our most prized possessions. We critically depend on sight for gathering most of the information about our environment and one could readily see that in the work environment, where hazards abound, the need to process the information becomes acute.

The present OSHA requirements are based on ANSI standard Z87.1-1968 "Practice for Occupational and Educational Eye and Face Protection." The main feature of the existing standard, with reference to impact resistance of spectacle lens, is based on the requirement that the lens withstand an impact force derived from a steel ball, 1" diameter, dropped from a height of 50 inches. The velocity of the steel ball on impact computes to be about 16.6 ft/sec, and as a result the kinetic energy imparted to the lens, with the ball weight of 2.5 oz., is 0.64 ft-lb. Now let's consider industrial operations involving high speed cutting, grinding, milling and drilling. The kinetic energy at impact for an ejected carbide steel sawtooth can be computed as follows. The peripheral velocity of the saw blade is given by

$$V = \frac{(\pi)\ (d)\ (rpm)}{60}$$

where:
V = peripheral velocity, ft/sec
d = wheel diameter, ft
π = 3.14
rpm = revolution per minute

For a saw blade 12 inches in diameter traveling at 4000 rpm, the velocity is:

$$V = \frac{(3.14)\ (1)\ (4000)}{60} = 209 \text{ ft/sec}$$

For an ejected sawtooth weighing 2 grams (0.004 pounds) the kinetic energy at impact is:

$$K.E = \frac{1}{2}\ \frac{w}{g}\ V^2 = \underline{(0.004)\ (209)^2} = 2.7 \text{ ft-lb}$$

It is apparent from the above example, which relates a common occurrence, that the kinetic energy of a flying particle can be four times that which safety lenses are required to withstand under the present standard for eye protection. It would seem reasonable, then, to expect that the design of safety lenses, for protection against particles possessing kinetic energy, be based on information derived from ballistic tests. At the present time, no such requirement exists.

In another area of eye protection it is necessary to examine the adequacy of Table 1 in the Z87.1-1968 standard. Table 1 calls out shade numbers of absorbing lenses and the required transmittance for these shade numbers in the ultraviolet, visible and infrared portions of the spectrum. The requirements are based on the only good absorbing lens materials which were available for use at the time Table 1 was first generated, during or before the 1930's.

An obvious deficiency of Table 1 of Z87.1 is the fact that it places no limits on ultraviolet transmission in the region from 200 nm to 300 nm which is known to be very effective in damaging the cornea (photokeratitis). Another shortcoming in Table 1 is that all infrared radiation from 700 nm to the limits of glass transmission is lumped into one integrated measurement. It is now known[15] that the wavelength region from 700 to approximately 1300 nm is transmitted through the ocular media and is absorbed in significant doses in the retina, while radiation of wavelength greater than 1300 nm is absorbed before reaching the retina. Allowable infrared transmittance of the filter should, therefore, be split into two values: wavelength regions shorter and longer than 1300 nm. (This has been done in the ISO Standard for welding filters (ISO/TC94/SC6, April 1973.)

As a result of intensive scientific work carried out in the last three decades (nuclear bombs, lasers, and space exploration) much work has been done to quantify Tolerance Level Value (TLV) data for human eye. A very thorough review of this work may be found in papers by Sliney and Freasier[16] which contains a list of ninety references to earlier work. A more recent work by Pitts[17] updates TLV knowledge in the 200 to 300 nm region. In a spectral region where few measurements have been made of eye sensitivity to radiation, the 300 to 400 nm region, NIOSH is presently supporting research carried out by Doctor Pitts. It is expected that with the availability of data in these critical regions, the design of eye protection against radiation hazards may contribute significantly to the reduction of eye injuries from such hazards.

Another aspect of the eye protective equipment is that of quality control - an integral part of any good design and manufacturing process. In recognizing the need for strong relationship between effective quality program and worthy safety equipment, we are involved in a research effort which delineates such a relationship. The research is aimed toward the development of criteria for physical defects (such as trapped bubble and striae) and mechanical defects (such as rough edges) classified as Critical, Major A, Major B, and Minor. For example, any defect in lenses which is likely to result in a condition immediately hazardous to safety and health of the user is to be classified as Critical. The other classifications are defined proportionally downward.

The total quantitative lack of such specifications in the present Z87.1-1968 Standard is one of the standard's major shortcomings. It is expected that the quality control classifications, once fully developed along with their correlative test methods, will become part of the design and performance criteria for eye protective equipment. As such, it will be suitable for employment by manufacturers and by any accredited laboratory engaged in testing and certifying eye protective equipment.

ASPECTS OF MOTIVATION

The subject of human needs has been discussed by many researchers and it became further delineated with the emergency of the Industrial Revolution. Maslow's[18] classical theory of needs, when viewed from the personal protection angle, seems to provide additional insights to the subject of employee motivation with regard to personal protection.

Maslow identified five levels of need hierarchy. They are, in brief, the following:

1. Physiological Needs: This need is the most basic in the hierarchy. The needs of hunger, thirst, sleep and sex fall in this need category. According to Maslow, once these are satisfied they no longer motivate and, therefore, the person will strive for higher level of needs.

2. Security Needs: The second level of needs is of great interest to all of us who are involved in occupational health and safety. This level of needs stresses the emotional as well as the physical safety. Studies have shown that unless security (safety) is satisfied, people will not be concerned with higher order needs. This implies that the physiological and safety needs are fundamental needs ingrained in each of us.

3. Social Needs: This third or intermediate level of needs loosely corresponds to the affection and affiliation needs. It is essentially a need that we all have to belong and to be accepted.

4. Esteem Needs: The esteem represents the higher needs of man. The needs for power, reputation, achievement, and prestige can be considered as components of this level.

5. Self-Actualization Needs: This level represents the culmination of all the lower, intermediate and higher needs of man. A person who has become self-actualized is self-fulfilled and has realized all of his/her potential.

The needs hierarchy is presented in this paper since it is considered to be relevant to worker motivation and workers usage of personal protective devices. If we accept the premise that security (safety) needs are rather fundamental to the welfare of the worker, we can then examine the next level of needs - the social needs.

One thing that we recognize and experience is the fact that we live in a midst of drastic changes in people's expectation. This is true almost everywhere, but with the passage of the Occupational Safety and Health Act of 1970, nowhere is it more forceful than in the work place. Many workers in the professional and managerial groups find it relatively easy to meet their basic needs. At the same time, although perhaps to a lesser degree, blue collar workers also find these basic needs fulfilled and as a result they became relatively secure about them. But in order to obtain an acceptance of our safety concepts and programs, such as the usage of personal protective devices, we are likely to find that it is necessary to create and maintain a social work climate which lends itself to the fulfillment of the social needs among workers. We are likely to find that the work practices need to stress the social acceptance of personal protective devices by making it fashionable to wear and use such devices. In the final analysis it is the social climate that management and labor create for safety and health which will have the largest impact on the reduction of occupational injuries through the proper design and usage of personal protective devices.

CONCLUSIONS

The central issue of the research activities in the field of personal protective equipment is, and must remain, the need to provide effective protection of the worker at his/her work station. There are several approaches available to achieve such a goal and these approaches depend on the particular work tasks and their related hazards. However, often the protection of the worker could be afforded only by means of personal protective equipment. For this reason, it is necessary to bear in mind that the design of the personal protective equipment, to be truly effective, must be based on real world performance criteria and on medical research data on human tolerance to assaults from occupational hazards.

As a national institute, we are directing our research efforts to develop suitable criteria for personal protective equipment standards which:

(a) Are substantiated by scientific research and engineering test data.

(b) Consider the entire spectrum of human factors and thus "humanize" the standards.

(c) Strive for acceptance and usage of personal protective equipment by workers

(d) Are devoid by any ambiguities in the definition of terms used in the standards.

(e) Provide for technically-sound, feasible, and realistic test methods and procedures.

SUMMARY

The development of performance criteria as the basis for the design requirements of several personal protective equipment is being discussed in the paper. It is pointed out that the state of knowledge on the tolerance of human beings to assaults from work place hazards is not well established. As a result, many design aspects of existing standards of personal protective equipment are unrelated to the real world hazards and, therefore, the effectiveness of the protective equipment remains questionable. Several examples, reflecting present research efforts in the area of personal protective equipment, are presented and discussed in the article.

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