

ILLUMINATION LEVELS AND SAFETY

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Dr. Grimaldi: I feel a little bit this morning like a sultan who walked into his harem and knew what he wanted to do but did not know where to start. Yesterday, I was a little more sure of myself, but now I am much more uncertain.

We have a number of demanding considerations as we approach this very important subject. One is the responsibility that is given to us as a result of our participating in a conference of this kind. We are a handful of people, but I think the influence we have can be tremendous. I am mindful of GSA's first order, for example, covering the requirements for the purchase of automobiles, and, on the strength of these standards, literally influence the whole development of the technology with respect to the design of automobiles for private passengers. Shortly after that, some six or seven years after that, GSA became very much interested in the design of buildings to protect the personnel from the fire hazards that many buildings will contain and, on the strength of that particular conference and recommendations, GSA was influential in changing many of the community standards with respect to building construction. About two years ago this time, I think it was, GSA had a conference on the environmental problems that are associated with the design of big buildings and locating them in major communities, and, on the strength of those recommendations, a whole new series of points of view were developed with respect to environmental control. I believe we might see the same kind of development coming forth from this kind of conference today, even though the numbers of people involved in this one are much smaller than the other two GSA conferences, and, also, because NIOSH, in this particular instance, has been brought into the important problem areas, since it has the professional responsibility for developing the points of view that are needed in order to

effect worker safety and health correctly.

When we talk about safety, we always had a major difficulty, I think, largely because most of us do not understand what it is we want to do. I think we have to consider very carefully what I believe is a fact. That is that all that we do in safety is largely the development of a feeling of intolerance about the injuries that occur in the various areas that our work and safety have taken us into. We speak quite sincerely, I believe, about accident prevention, which literally means, to me, the elimination of all injury; and, in industry, we are talking about, in many instances, the control of those things that affect the worker almost down to the discomfort level. We had an interesting discussion yesterday, which led me into my little sultan story, which pointed out that we are concerned not only with the serious effects of illumination and reduction of the levels that might occur, but also with those things the worker might be bothered by as levels of illumination are reduced. And safety is sincerely concerned about that wide spectrum of events that might occur with respect to the effects on people.

But, at the same time, society is not that much sincerely concerned with the subject, I do not believe. All that we have been able to do in safety has resulted from an emergent concern on the part of people, large numbers of people or representatives of people, over things that seem to affect the public seriously. What I think we have to concern ourselves with, as we discuss the effects of reduced illumination levels upon people from the practical point of view and with regard to the needs of worker safety and health, is that very serious, almost schizophrenic position, in which safety people find themselves; that is, at any particular time, how much safety is needed or how much is going to be bought.

The serious exposure is the one that seems

SAFETY AND HEALTH EFFECTS OF REDUCED ILLUMINATION

to develop the most interest in safety. The less serious exposure is the one we talk about in great substance and great amounts but, at the same time, we give very little support to. I can give you the book and verse with respect to many, many kinds of ventures, including congressional hearings, with respect to that. Therefore, in our discussion of illumination and the levels that might be of some interest to us as we try to save power and the effects of these changes on worker safety and health, we have a number of concerns, I think, that affect us.

I will assume, first, that we are not discussing illumination levels below those specified for safety in the American National Standard Practice for Industrial Lighting, A11.1, 1973. These, I remind you, are one-half to one foot-candle for areas of slight hazard and two to five footcandles where the hazard is considered high. Now, in this instance, we are talking about the amount of illumination that is needed in order for people to avoid those hazards that they might run into, fall down into and in other ways be exposed to, which are sources of serious injury. This is quite different from the points that we were talking about yesterday, in some instances, that were related to discomfort.

The standard in Section 6, which is devoted to safety, logically states that "Any factor that aids visual effectiveness increases the probability that a workman will detect the potential cause of an accident and act to correct it." Unfortunately, there are a number of variables affecting visual effectiveness besides simply the level of illumination. Some of these, as you know so very well, are direct glare, reflected glare from the work, harsh shadows, and excessive visual fatigue. Some injuries may be prompted by delayed eye adaptation which occurs when moving from dark surroundings to bright ones. These effects and others have to be considered where the cause of occupational injuries is attributed to inadequate illumination levels. For the sake of simplicity, however, I shall limit myself to a presentation of what I know about injury possibilities associated only with low levels of illumination.

In considering the effects of illumination on occupational safety and health, there may be several injurious outcomes if the lighting levels are deficient, that they are too reduced, if you will. One, I suppose, is the effect on the eye after prolonged work in the field where the

illumination level is marginal or submarginal. Whether this is a significant problem, I shall leave for Dr. Cogan and Dr. Fry to resolve. Another is the injurious result of being unable to see a hazard and avoid it. Third is the possible psychological and physiological stress that may occur from working under too low levels of illumination.

Many studies have been reported on the effects of illumination. Some relate to the purpose of this discussion, although most were concerned with work production or performance. A two-step illumination improvement plan in one heavy manufacturing company—reported by McCormick some years ago—was followed by a decrease in the accident rate. First, the illumination in the erection shop was increased from five to twenty footcandles. (Notice the low levels.) Later, the shop was painted for better light usage and a more favorable brightness ratio. Accidents in the shop dropped thirty-two percent after the lights were changed and dropped an additional eleven percent after the painting. We do not know, however, what the long-term effect may be on the shop's accident rate. Also, there is some reason to question the competency of the particular investigation. It was not really a very well-done piece of scientific design.

It appears interesting, nevertheless, that a significant improvement in the injury rate was noticed when the illumination level was raised from the minimal five footcandles to the somewhat better twenty footcandles. The standard minimum for such tasks is fifty footcandles (structural steel fabrication, A11.1, 1973). As you know, this is for young adults with normal or better than 20/30 vision (corrected). We have no information on the age of the sample population or other limiting factors that might occur in this particular piece of information that was reported. In fact, most of the investigations in this subject area may be criticized for inadequacies in their experimental design.

The significance of the problem, however, with respect to the occurrence of injuries, would seem to be substantial. The National Safety Council, for instance, estimates that insufficient lighting was the sole cause for five percent of all industrial accidents and that, in twenty percent of the industrial accidents, poor illumination and eye fatigue played a part. Again, we have no good scientific information to go on with respect to those estimates. These

are, I think, largely estimates drawn from reports that are given to the National Safety Council from its members, which largely are based upon the information that is prepared for the implementation of Workmen's Compensation claims. The literature reports many instances where injury rates have been reduced by improving illumination and color. Considerable reductions have been claimed in shipyards, foundries, large assembly halls and mechanical workshops. However, there were no reports, apparently, on the effect on injury rates of a lowering of the illumination level. In other words, we are talking, in most of these instances, about low illumination levels to begin with. What happens after you reduce the illumination, we do not know much about. And, we have only the one case that I mentioned where the illumination level was improved and the accident rate seemed to improve.

One must wonder whether, in this case, the Hawthorn Effect was occurring. And we have to consider, also, the attitude of the worker, which may be a significant factor in the accident causation process. His preferences may influence his corroboration and therefore augment or vitiate his safety performance. What he likes may be what he thinks is correct. And this is, I believe, a serious consideration for us. It touches upon Mr. Caplan's interest when he asked about relatively minor injury occurrences, such as discomfort and headache, issues that concern us in safety, but, as I said earlier, which we have a very great difficulty in trying to attack.

One part of a study, a number of years ago, attempted to determine the effects of variations in illumination on production. This is a classical study. I will just mention it to illustrate my point. Two girls who wound coils were isolated in a special room and their productivity was charted. First, the amount of light was increased regularly from day to day and the girls were asked how they liked the change. As the light was increased, they told the investigator that they liked the brighter lights. Then, for a couple of days the girls saw the electrician change the bulbs. He merely removed the bulbs and replaced them with others of the same size, so the lighting levels were not changed. The girls, however, supposed that the lighting level was changed, stepped up in this instance, and they commented favorably on the additional increase in light. After awhile,

the investigator started decreasing the amount of light from day to day, again asking for reactions. After a period of such decreases, the bulbs were changed without decreasing the light. The girls then commented that the further reductions were not pleasant and that they preferred more light. It is interesting to note that production, in this instance the amount of work done, did not change materially at any stage of the experiment.

One criterion that has been used in illumination research is the measured visual acuity of people under varied levels of illumination. Luckiesh and Moss, for example, have shown that visual acuity in reading tasks improves with increases in illumination from one to ten to one hundred footcandles. It has been shown, also, that visual acuity improves, under some circumstances, up to and beyond a thousand footcandles, although the curve tapers off noticeably around ten footcandles, with only slight gains beyond twenty footcandles. Tinker, in commenting on this criterion, points out that gains in acuity with high levels of illumination are so slight as to be of no practical consequence. Also, he criticizes Luckiesh and Moss for not investigating the effects on acuity of illumination levels between ten and one hundred footcandles, expressing the view that there is probably a level between these beyond which no practical gains occur.

Now, you had good evidence of all this yesterday. I am repeating largely, in this instance, I think, mostly what the industrial engineer would be taking as a position with respect to the information that he has in approaching this problem of safety and what is needed with respect to design considerations in occupational situations. Speaking further of visual acuity as a criterion, Tinker states that, if visual acuity is accepted as a criterion, there is no justification for suggesting that more than forty to fifty footcandles are necessary for adequate discrimination, even for tasks that approach threshold discrimination. This begins to approach the standard that we are considering these two days.

On the other hand, Brozek and Simonson studied performance of a two-hour visual inspection task at three levels of illumination—five, one hundred and three hundred footcandles. Significant differences were found for performance, performance decrement, average eye blink rate and change in the recognition

SAFETY AND HEALTH EFFECTS OF REDUCED ILLUMINATION

time for threshold size dots after work at the different brightnesses. Although the effects of illumination levels on visual acuity and task performance has not been correlated with safety performance, the implications for accident causation cannot be disregarded. It would seem that shop illumination levels which are satisfactory for work performance should be adequate for safety. In this regard, Lythgoe's observation, that very slight gains in visual acuity are obtained beyond twenty footcandles, may be of interest when considering the effects of lowered levels of illumination.

Physiological costs of differences in illumination levels have been reported. Luckiesh and Moss observed greater decline in heart rate during a one-hour period when people read under one footcandle compared to one hundred footcandles. Luckiesh and Moss had subjects, while reading, rest two or three fingers on a large, flat knob of a concealed key. They were instructed to press the knob after completing the page. The purpose of the concealed key was to mask the real reason for the knob, which was to measure pressure continuously. The average grams of pressure exerted under one, ten and one hundred footcandles was sixty-three, fifty-four and forty-three respectively, implying less tension for higher levels of illumination. Tinker and Bitterman questioned the conclusion that the results justified one hundred footcandles for the reading task, largely because very slight changes occur beyond twenty-five footcandles.

This synopsis suggests that, while illumination levels can be expected to influence the worker's safety and health, the safe levels probably are within the visual acuity requirements for task performance and that the minimums for such requirements are uncertain. When considering the effects of lower levels of illumination, it must be remembered that the quantity of illumination is not the only significant factor. A visually safe installation must be free of excessive glare and uncontrolled large differences in luminance within the area. In the latter instance, this is necessary to avoid temporarily noticeable reductions in visibility because of changes in eye adaptation when

looking between areas of light in different luminances. I am just reinforcing, I suspect, your position on this one. Also, it needs to be recognized that there are still some loose ends and unanswered questions concerning the determination of illumination standards. Many of the recommendations in ANSI A11.1 are probably in disagreement with the implications of other research; for example, Tinker and Blackwell, to a certain extent, and others.

Moreover, it has been suggested that lighting can weaken information cues. Logan and Berger found that the "visual gradients" of a pattern density of objects being viewed is suppressed in high levels of illumination. Therefore, to the extent that this might be so, more footcandles of illumination might reveal less than fewer footcandles, such as by reducing shadows that characterize an object's features.

A word should be added about illumination for persons of below average visual acuity and for aging persons. No one mentioned Guth and Eastman and McNallis. They found that about thirty footcandles would provide a young group, seventeen to twenty years old, with the same visibility level as fifty-eight footcandles for a person sixty-one to sixty-five years old. So we have almost a two to one factor in terms of necessary illumination for older people in this instance.

Finally, a discussion of illumination requirements probably should not be ended without mentioning the effective utilization of light, particularly with respect to power conservation. Much of what we are concerned with in conservation is not light levels themselves but how to maintain the light levels, and strong emphasis on this area, I think, is important to consider in any recommendations that we might specify. It seems, therefore, that workplace illumination is not a matter of light output, how high or low illumination should be, but how to optimize the energy used with respect to a number of factors. In particular, the subject with respect to illumination conservation indeed seems to warrant further research before conclusive opinions can be formed.

Thank you.

DISCUSSION

Dr. Blackwell: I would like to make a rather, perhaps extended comment, if I might. Let me summarize it first and see if you want any more. Since I have spent about thirty years of my life collecting research data since the Tinker episode, I would like to bring some of this to your attention. Let me put it this way. We know, now, conclusively, I think, that the extent to which changing luminance levels or illuminance levels affects visual performance in any sense of the word depends critically upon the task and the conditions under which the task is performed. If one uses an acuity chart of high contrast and looks straight at it—which is what, of course, essentially what Tinker did in some of his experiments—now, we know that it is true that there is no advantage involved in going to higher levels. The task is so easy to see, so trivial, you can do it by moonlight, in fact.

Beginning in 1958 and ever since, I have shown that, on the other hand, if the task is more difficult — for one of two kinds of reasons, the task might be smaller in size or lower contrast, that is one kind of reason, or the conditions under which you perform it must be more realistic in the sense that you do not have all day to look at something that you see in front of your face, that is not real life at all—then a very different result occurs. Perhaps I overemphasized yesterday what is also true, which is that it is not at all a linear process. If one doubles the light, one does not get double anything in the visual domain, even under the most extreme conditions.

But I must say I do not think I can accept the conclusion that Tinker is all we know about visual performance. I mean, indeed, beginning in 1958, and now confirmed by research in countries all over the world, the points I am making are accepted worldwide. That is, we should not be talking about visual acuity charts which have nothing to do with real life. They are for refracting the eye. The Tinker experiments tell you one thing, and one thing only; where the task is extremely easy, you need almost no light. Therefore, I think we have to say that the extent to which one needs twenty or thirty footcandles or whatever it is, is strictly a matter of the task and the task conditions.

Now, it is always true that the advantage of increasing illumination is still relatively small.

Let us not go overboard. I have shown how flat those curves are, even for tasks that are quite difficult. But, as I say, since I have spent thirty years of my life putting Tinker out of business in this field, I really have to object to his experiments being used as the latest information.

Dr. Grimaldi: What I meant to do, Dr. Blackwell, I appreciate your comment by the way, was to try to give some relationship to the problem of injuries which might occur to workers due to inadequate levels of illumination. Now, based upon the information that we are presently working with, there seems to be a strong relationship between the level of illumination that is going to be satisfactory for workers in order to perform their jobs as they are given them, and the occurrence of injuries as they might take place in the work situation. Therefore, if we were to establish amongst ourselves what seems to be the best level for task performance, in terms of all the economies that are involved, I think we can be satisfied that worker safety and health has been satisfied as well.

Dr. Blackwell: When we speak of visual performance, we can take any particular case you wish; we can take any experiment that has ever been done on visual performance—I have a number of slides I did not show yesterday showing that experiments have been done all over the world. Now, those experiments all hang together. They all show the same thing I have been trying to say, which is that the extent to which ten footcandles is enough for visual performance depends entirely on what has to be seen and under what conditions it has to be seen. Now, to bring it to safety directly, in graphs I have that I did not show yesterday, we have evaluated errors in the visual performance. That is, an error in visual performance, as I say, is failing to see something. That is an error, we call it, of omission. One fails to see something that is there. In our desire to present the broad picture of visual work yesterday, I said nothing about errors; that is to say cases where a person failed to see something. None of the curves that I flashed on so quickly yesterday afternoon—if you observed them, they are logarithmic scales, perhaps you could not see this too well—go to a hundred percent; none of them go to ninety-

SAFETY AND HEALTH EFFECTS OF REDUCED ILLUMINATION

nine percent. All the data we have under realistic conditions go much, much lower than that. This means that every experiment that has ever been done that is realistic and not looking at an eye chart or looking at high contrast print, shows errors or failures to see. Obviously, whether that is a safety problem depends entirely upon what the task is.

Dr. Grimaldi: Or whether it is an illumination problem.

Dr. Blackwell: Well, let me say that it may be that illumination is the wrong way to solve it. I will always accept that. That is, if one can use a magnifier, one should not try to do it with illumination. But, assuming that we are discussing here that the industrial engineer has done his level best to make the task as safe as he can by means other than illumination, then we say what can illumination do. Illumination is, one must admit, a rather inefficient way to improve safety, because the curves are very flat. But, again, we have to say, how about it now? Suppose you have a situation which you have made as safe as you can, you can still ask the question, what does illumination do for this? And I think, if I were to dig out my curves and show them, that there are many situations that have been studied where, indeed, you would want to put light extremely high, in the nature of some of the levels talked about yesterday.

In short, you must decide what you must see for an accident to be avoided. If it is a moving lathe part near your hand—and this is low contrast and high speed—indeed, it may turn out that much higher light levels are needed. So, what I am saying, in short, is that, when it comes to safety in the sense of avoiding falling down a stairway—which is the case you quoted in the beginning—I thoroughly agree, very low light levels are sufficient. If there is anything we know, it is that the eye really is a remarkably good device and can do very well under low levels of light. You can wander around at night and do quite well, too. So that, if all you are trying to do is avoid falling down a stairway, not much light is needed.

Dr. Grimaldi: I think we are saying the same thing. At the risk of giving you an excellent fifteen-minute talk in forty-five minutes, I will try to say a little more of what I tried to cover quickly. Sometimes I make the mistake of believing that subtleties will get across.

Remember, my opening two or three sen-

tences had to do with the relationship of the injury control problem to severity. I say that we are concerned with all of the injurious consequences that affect people and safety in general. With respect to the worker, this is literally the edict that has been given to us by the Williams-Steiger Occupational Safety and Health Act of 1970. I say that society does not appear willing or able to pay the price for controlling all of the injuries. For this reason, a cutoff point arbitrarily is determined. Whether we determine it or not makes very little difference under the circumstances, because if we do not determine the cutoff point ourselves, it is determined for us.

With this interest in severe exposure in mind with respect to the worker injury problem, we may relate our concerns about illumination to those aspects of illumination devoted to what is needed for the worker to do his job well, if they are in keeping with the injury control needs that must be satisfied. As long as the many considerations involved in worker performance are included in the recommendations that will evolve from this conference, I think, from the point of view of worker safety and health, the chances are we will have satisfied all the needs that have to be met. I am not taking a categorical fifty footcandles as necessarily that level that will cover all the illumination needs for all the workers throughout the nation; but, I am saying that, at that level, there seems to be some evidence that maybe this was good in the first place. There are, of course, exceptions that must be considered.

Dr. Yonemura: I believe that your laboratory brought out the fact that the word "safety" had, instead of a positive connotation, a highly negative connotation. The minute you mention safety, people think about death, injury, and what not. The point I am trying to bring out here is that you said that, right now, you can talk about a lot of other aspects but can not do anything about it. People do not accept it; it is not good enough. Now, when you talk about safety, you get adverse psychological effects because people have this highly negative connotation and feel very upset the moment you talk about safety. This brings up the other side to a much greater extent and it should be considered. By this, I mean not the performance aspect but the preferred aspect, or the psychological effect, of low light levels. We do not care. He is not going to get hurt; he can see

all obstacles. But, darn it, if he feels he is going to bump into something, he is scared. And, if the safety effect has a very strong negative connotation, the implication here is that it is an important element for a worker. Should this aspect not now be given a lot of weight?

Dr. Grimaldi: Well, I am not so sure, Dr. Yonemura. I am not a psychologist, as you certainly know. I have been in industry for a long time as a plant engineer and a consultant for health and safety for General Electric for twelve years before I moved to New York University. I believe that, in general, unless there is a severe hazard confronting a worker or an administrator of many workers so that it is quite clear that there is no option as to what to do, because the results otherwise would be inevitable and immediate, most people are inclined to feel the issue of safety is something that is not at the moment of great concern for them.

Dr. Yonemura: About the time of the early fifties, 1955 I think, you people were at the top at that time in safety studies. If I recall correctly, this was a concept that automobile manufacturers wanted to use, to advertise safety instead of power. And they had to abandon it because of the negative connotations that it had. So I think the things you talked about would be refuted by this survey.

Dr. Grimaldi: I am turning it the other way around. I am saying that safety, now, is something that people, from time to time, generally are inclined to discount if they do not reject it altogether. Dr. Mead will talk about this later, I am sure. This would be an awful world if all of us were concerned about safety all the time. We would live in holes in the ground, I suppose. But, where the issue is severe, serious, then we are concerned. And that is where the direction in safety always has been placed, whether we want it to be placed that way or not. That is the way safety has evolved, and it is that issue that I am bringing forth. It is a major handicap in hazard control planning.

Dr. Mead: I would like to amplify your comment with respect to the seriousness with which society regards safety as an element under the control of people, using the automobile fatality situation as an example. In this country, sixty thousand people a year are killed on the highway. There are two things you can do that would reduce this by at least fifty percent. One is to be more severe with how you treat the drunken driver and the second is to

enforce laws to reduce the speed of the car. If you can control those two elements, you can do remarkable things. But, evidently, we are willing to pay the price of sixty thousand deaths a year plus hundreds of thousands of injuries and billions of dollars of cost.

Dr. Grimaldi: It is significant on that one point alone, that the nation never took much interest in federalizing speed rates on the nation's highways until the energy crisis emerged. And now, with a 55 mile edicted speed limit, not necessarily held to explicitly everywhere but, nevertheless, more uniformly held to than ever before, you notice that we are having the remarkable reduction of twenty to twenty-five percent in the number of fatalities on the road.

Dr. Mead: I would just like to raise the question about illumination on the highways, also. There is some evidence that, indeed, there is a rather direct relationship between illumination and accidents. The work being done at Franklin Institute in Philadelphia is very convincing. They have a segment of highway in the middle of the city over which they have very strict control over the amount of illumination, spacing of the lights, and so on. And they have been doing things like throwing things out in the street to see what people will do. And they are getting correlations in the eighties between what people do in the car and illumination. That is the highest I have ever seen.

Dr. Grimaldi: By the way, you might think it is irrelevant to talk about the automobile, but we can also talk about automobile lamping, itself. And remember, if we just bring this up and forget it from now on, that about twenty-five percent of the occupational fatalities occur in motor vehicle situations, people who work and drive at the same time, in other words.

Dr. Weale: I am surprised at how we are beating about the bush. The arguments which have been produced in the last five minutes seem to fall into political and nonpolitical ones. It does not matter politically if someone gets killed on a pleasure ride, but it may matter politically if a worker gets killed and the trade union gets up in arms. It seems to me to be resolved quite simply in those terms, and what matters from the point of view of illumination, is neither here nor there. If illumination is politically convenient, then the authorities are going to produce it; if it is not, they are not going to.

SAFETY AND HEALTH EFFECTS OF REDUCED ILLUMINATION

Dr. Grimaldi: Well, that is not quite right, Dr. Weale. What I tried to say is that the mere technicalities of what might be best for safety and health are not necessarily apt to be implemented unless they fit the public's interest in what it wants. The two are very closely related. If we applied all that we know about controlling hazards, we probably would have very few injuries occurring. But it is true, you know, that we have repetitions of serious events regardless of the standards, regardless of the force of law behind them, regardless of the sanctions that have been written into the forces of law, only because society is willing to tolerate something more than what we specify as scientists and technicians for the sake of safety.

This is an important consideration and it is, I think, related to the criticism nicely presented to us that you gave yesterday. You said that our lighting levels are, by standard, much higher than they are in the U.K. Why should this be so, and are we, indeed, correct in calling for all this? The point is that, in this country, we can afford to do it and the public is interested in having it that way and, therefore, it gets done that way.

Mr. Caplan: It seems to me, Dr. Grimaldi, in your discussion here of accidents and the relationship of illumination to accidents or injury and so on, that what you are really talking about is decision-making. In other words, a decision made in *performance* may not have an effect on an accident. You decide whether to pick out this one or that one and you have quality control—a good piece of equipment or a bad one—is that apple rotten or not. It is really not a safety problem. But if your decision is based on whether or not you see a valve reading, if you are a nuclear reactor operator, for example, if you see it and take action that will prevent an injury or accident, that is important. The same thing with traffic control, for example, at an airport. There, performance is directly related to accident or injury. But I would like to know if there has been any correlation between decision-making ability related to fatigue, for example. I know there has been some related to age. It was said yesterday that decision-making capability decreases as one ages—what is the exact correlation between decision-making ability and illumination? I think this might be more of a relevant subject.

Dr. Grimaldi: I am sure that somebody has in-

vestigated it, but I do not know of any studies of this kind.

Dr. Halldane: I would like to support a point that Dr. Blackwell made a little while ago. He started talking about failure as against the probability of achieving something. In other words, performance generally is considered as achieving correct scores types of concepts. Now, in psychology, we also generally put in the assumption that failure plus success is unity. This is a general misconception, because in a conservative type of system it would work. Unfortunately, it does not work in our systems that way. I came across an article in *The International Lighting Review*, but I do not know the source of the information. It is a glaring point and it shows performance going up slowly as lighting increases but failure rate decreases very sharply with increasing luminance. And here, it tends to be significantly limiting, about three hundred lux, which is about thirty foot-candles. So, if you took a criterion, in our words a response criterion, and in this case an overt behavior of doing something or other, or if it is a cognitive decision of getting right answers of, say, reading and asking something, if you went by the failure to do something or other, it would be a more limiting criterion for NIOSH and GSA's purposes than would the Blackwells' work of successful performance.

Dr. Blackwell: We completely agree with you. It so happens I have with me a report that does this. In our recent experiments, we have appreciated this point and have set up a program in which we have measured three measures of human performance. First was the percent of correct acquisitions of information, the second was the errors of commission as we call them—one says something is there that is not there—and, third, the errors of omission—one fails to see something there that was there.

Let me be specific. If one had an array of five rings, the specific thing we are using at the moment, and we ask the following question of the observer. "These rings can be of eight orientations, each one of them. Now, you look at the one in the center first, and it is in one of the eight orientations, and then you give me the following information: Is any one of the other four in the same orientation as the one in the center and if so, which one?" The answer then is "None," or "North," "South," "East," or "West." Now, we did this on purpose because

we wanted to show by direct experiment—we have done it, the data exists now on fifty-eight observers in the new standard data that I did not talk about yesterday, but we hope we can have you all use it and we sent it to Dr. Ross because this is what we think must be done—exactly your point, that, as visibility level goes up—meaning, of course, as luminance goes up, all other things being equal—there is a change in the three things and the changes are not at the same rate. And we say that the criticalness of the task—that is, how serious an error it is—can be evaluated differentially. So you can subtract out either errors of omission or errors of commission and you can place different weights on them. This is all now a fully developed technology. We have the data right here in this document that I hold in my hand, which was CIE approved last month. And the point is I thoroughly agree. And this is why we said criticalness is one of the variables involved.

Dr. Halldane: What I was trying to emphasize is the human response. Now, let us differentiate here in terms of our basic evaluation; then we can interpret your data and utilize it correctly in terms of application.

Dr. Blackwell: We feel we do have a way of describing human performance. If you know what a task is and what the criticalness of it is in terms of errors as well as successes, you can take these data, place them in the proper weights, and use that as a tradeoff curve. This is exactly the idea we had in mind.

Dr. Halldane: You see, I am thinking of your case where the error is more important than correct performance. And so that data would be more pertinent than the performance data.

Mr. Caplan: That error can be of two types, either an error of commission or an error of omission.

Dr. Blackwell: Right. Of course, in safety, it could be either.

Mr. Caplan: If you do not see a sign on a radar scope, that is an error of omission. If you do not see it, that can be just as dangerous as seeing a false blip.

Dr. Blackwell: I am staying up because I want to make a general point that may surprise you. Your general point, of course, that if one satisfies performance criteria, one expects to more than satisfy safety criteria is a general point of view that people have. And, as I point out, this makes good sense in certain classes of

situations involving accidents. The point was made that I was trying to make: that there are cases where, indeed, safety and serious injury may be a more critical factor than the performance. I have been brooding over what you all are going to do in a practical sense with the horrible facts we presented yesterday afternoon, the horrible facts related to the individual differences. If people are as different as we say they are—and we maintain we have separate experiments in three different countries to back up that—then what in the world can we do from a practical point of view?

I want to tie this in with the discussion of accuracy in the following way: You can argue, I suppose, that leaving aside performance errors, which are safety matters—these are not too frequent, I fully agree with that—let us suppose that, if we were decision-making here for the U.S. government and had plenty of time to consider all these data, and let us suppose we decided that from a performance point of view it is sheer economics—lights buys you something, it buys you performance—people differ—this is unfortunate but this is true—what attitude are you going to take? Let us talk about seventy-five percent of the population. Let us accept the fact that we can not possibly give all the people high performance rates. There are also a lot of other reasons people do not perform well. Some are just lazy. Some are stupid. There are lots of reasons why people do not perform, so why worry about it? In other words, decide something about a tolerable portion of the population to give a tolerable and reasonable amount of performance. Suppose you did that. Suppose you ended up with fifty footcandles for the young and a hundred for the old or whatever it might turn out to be as a practical solution.

Now, suppose you then come to two other considerations, which is supposedly our business here. One is safety and the other is health. Under most circumstances, I agree with your main point; that is, under most circumstances, excepting the really dangerous serious injury effects, undoubtedly, a safety criterion would be satisfied by less light as the ANSI safety lighting levels indicate, one footcandle. I believe the work we did yesterday suggests the same is true of health. I do not myself, believe that there are going to be heavy symptomatic complaints if lighting is

SAFETY AND HEALTH EFFECTS OF REDUCED ILLUMINATION

reduced to the level of VL 7.29 on the average. I do not really believe that.

Now, suppose you all decided from the point of view of performance that VL 7.29 is as far as you want to go. All right, question: What about the safety and the health criteria? So what I am saying is, for the average, for the seventy-fifth percentile you might use for performance, that I think it might be true you would have satisfied the safety and health requirement by satisfying the performance. But, now comes the question of the extreme observer. On the average, I think it is true that to satisfy performance criteria is to always satisfy, with the same numbers of people, the safety and health criteria. It can be worked out that such a lighting standard, in effect, protects a rather large number of the population against the other two hazards. You might be able to say a lighting level of fifty foot-candles—or a lighting level of fifty for persons below forty-five years of age and one hundred for persons above forty-five or whatever is the maximum value—gives a pretty good performance for the public as a whole. It protects you all the way down to all but ten percent of the people in terms of ordinary safety aspects that are involved. It might protect you all the way down to ninety percent of the population against health considerations. So that, in my own mind, what I have been trying to say is what do we do about the individual differences? Maybe this is what we do about it and whether you tell anybody about this is really quite beside the point. We care. We are trying to decide what to do. In general, I agree with your point, but there are exceptions, as Mr. Caplan pointed out.

Dr. Dukes-Dobos (NIOSH): I think that the main aspect discussed and the main emphasis was put on the question whether at a given level of illumination a worker can observe or notice a change or any motion in his environment. I wonder whether we should look at the question from another point of view that Mr. Caplan mentioned before, namely, to what extent an accident may be due to the fact that the worker cannot make the right decision because of the strain and consequential fatigue which was caused by unsatisfactory level of illumination. I do not know whether or not data relating to this question of illumination are available in the literature. I know, however, that in the area of heat stress it has been

demonstrated that, if you expose a worker to experimental conditions, wherein the subjects are given a task requiring problem solving, the higher the required mental performance, the more definite will be the reduction in performance due to heat exposure. In other words, the higher mental responses are more sensitive to strain and consequential fatigue than the lower ones. I wonder, if you look at the question from this point of view, will you end up with a different decision concerning how illumination affects safety and health?

Dr. Grimaldi: The National Safety Council has estimated that twenty percent of industrial accidents are associated with illumination in some way. This may be fatigue; that is part of the problem. It may be that the levels of illumination were so low that hazardous objects were not discerned correctly or it may be that unimagined reasons are responsible. We do not have good information on this at all. The fact that twenty percent is used as a figure indicates that there is a significant number that seems to be associated with this problem.

I think that the other side of this, though, is something of interest. There are a large number of plants in the United States, and when I say "large number" I do not mean the majority, the number may be as high as eight or nine percent, perhaps, where the lighting levels are so far below the standard that now we are talking about levels that are really at the danger point. These may be the contributor to that twenty percent figure. Unfortunately, the information we have in this whole area of safety, of worker safety and health in particular, is very sketchy. It has never been developed well. This leaves us quite at a loss. In general, there are no bad decisions in this kind of area that we are exploring, just bad information. If we had the right information, we could come to the right decision all the time.

Chairman Heins: It is my understanding that the National Safety Council's figure of 20 percent of industrial accidents associated in some way with illumination is not based on sound scientific data, but rather is based primarily on accident reports filed by numerous different persons. When a foreman or safety officer files an accident report and states that the cause of an accident was that the employee tripped and fell over an object because he did not see it, this does not necessarily indicate that the

illumination levels were inadequate, although this accident would most likely be included in the 20 percent figure. Let us attempt to channel our discussion toward obtaining the necessary scientific information. If the twenty percent figure is correct, it is too high. What type of research or what activities should we undertake to alleviate this problem?

Dr. Weale: What procedure exists in this country for reporting industrial accidents? Are you under statutory obligation to report or is it due to insurance information or what?

Dr. Grimaldi: There is a statutory requirement under OSHA, which all employers are required to comply with. Before that, there was, under the Bureau of Labor Statistics, an annual acquisition of work injury data from a sampling of employers in the United States. The Bureau of Labor Statistics is composed of some very competent statisticians. After the survey was initiated, if there were failures to respond, a follow-up was made to the employer so that the sample that they used was as complete as possible when reporting the data.

In addition to that, every state in the United States now has a Workmen's Compensation statute. In the United States, this Workmen's Compensation essentially is the state's responsibility. Under the requirements of Workmen's Compensation, data reporting and recording are necessary in order for the worker to be indemnified.

The problem, however, is that we have never really identified what it is that we are looking for when we talk about accidents. For example, there are "accidents" and there are events which we are concerned about which are not accidents. Some significant number of the cases, indeed, are accidents; and these are beyond our control entirely. The only cases we can do anything about are those events that are predictable, where we know the possibility of occurrence because of the causes that we have so much acquaintance with and, also, where we know something about how to correct the conditions of occurrence. These represent, in my view, something as high as ninety-five percent of the cases that we are dealing with. Most of the cases that we are talking about are not accidents at all, but simply unwanted events that are occurring because of failures in our control system.

The data that we are getting today do not differentiate between these classes of occur-

rences. But, as long as there are cases that are occurring outside the control of the employer—and indeed there are when you talk about accidents versus those injuries that are controllable—the difficulty in handling accountability becomes immense. Unless you can keep accountability sharp and in itself well-controlled, the opportunities for effecting the kind of safety performance that is wanted, may be very, very limited.

Dr. Halldane: I have a very important point to raise, and we should not overlook it because it was brought up again by Dr. Blackwell. This is the problem of developing the criteria that you are going to accept. One of the things you should be looking for to get over this problem is to find a limiting criterion which peaks. I myself, Dr. Yonemura, and others have been interested in the concept of clarity because there is an illumination level where the function peaks. This could be used as a limiting criterion in design. Now, we do not have data to substantiate this at the moment, but the concept is important. If you have something that increases with illumination or luminance in the visual field, the function goes up, peaks, and comes down; or it increases and then goes up again. You can use the peak, or that transition, as your limiting criterion by which to design.

Now, the things that you are dealing with here at the present moment have not got those qualities. They are just a general increase. This means you are going through the struggle of trying to develop either a percentage of correct scores, some political percentage, or some proportion that you are going to accept. It is an endless task.

As one way of reflecting this, I got involved with technology assessment. Managers, who go through forecasting techniques and goodness knows what else, go through the mental tortures of trying to predict the unpredictable. And one way of putting this is through an illustration regarding criteria that depend on a hundred percent confidence, like jury decisions. A whole jury has to decide if a person is guilty or not. They will not permit one or two to digress from the decision; otherwise, they are going to go back again. This is very interesting. Now, correct scores in universities used to be fifty percent. If you got fifty percent for an average on that grading, you would pass. Nowadays, it is like seventy and eighty because

SAFETY AND HEALTH EFFECTS OF REDUCED ILLUMINATION

there are not enough places for people to enter universities or do particular lines of work. It is becoming a method of excluding things. To change bylaws of an organization, either a majority or two-thirds vote is required.

So, what I am pointing out is the criterion seems to be reflected upon how the **people perceive the severity of the problem**. And I think this is the correlation that we, perhaps, can ask. What does the society perceive as the severity of the lighting problem? Then, once we can answer that, we are in a better situation to decide some percentage figure of what population we can agree to accept that we have encompassed. This, I think, might help us out of the problem of relating performance or figures to the severity of the problem perceived.

Dr. Blackwell: There is one set of data that does that; that is, to have observers sit down and set a rheostat to the preferred light level, neither too dark nor too bright, the experiments of Bodmann. We find that this one, indeed, gives us what you like. As you increase the luminance a little, more and more people say, "This is just right." The difficulty is that the value of illumination is two hundred footcandles.

Dr. Grimaldi: Also, though, Dr. Blackwell, there may not be, necessarily, a correlation between what they like and what they are looking for in the way of results. One other note of caution I should add. We seem to be slipping into a discussion which might suggest that we can make a scientifically wise decision based on what the military once called "expendability." When I speak of the severity of the problem, its seriousness, I am talking about the magnitude of the effect on even one person, not necessarily, simply a small number of effects on a large number of people who we might say that, just because there is no known way to deal with their vision limits we can ignore it. I don't mean to say we should ignore the problem.

Dr. Cogan: I would like to ask a question which I am not sure is appropriate. It seems to be relevant to what Dr. Blackwell says. What is wrong with the old experiments of Ives that he did under very practical circumstances? He measured the productivity of mail sorting under various levels of illumination. It was done under the auspices of the Public Health Service. Post office sorting was thought to be

representative of a fairly difficult task. It was done so long ago that many of the letters were not typewritten. There were different scrawls and contrasts were lower. It gave a rather good cross section of a difficult task. He found that, under different levels of illumination, peaking of productivity was on the order of twenty footcandles illumination. It seems to me this would coincide with what Tinker's experimental results were and, in contradistinction to Dr. Blackwell's comments, were a very practical, realistic test. Now, what is wrong—why do we go above twenty, why do we go to fifty footcandles, if it does peak at around twenty?

Dr. Blackwell: There have been many experiments done since then and there is much other data now available. One takes the composite of all of them and looks at the tasks involved. Depending on the task and conditions, the answer comes out to be either one or a hundred. We have enough data to let you look at those and say which of these sets of data you think is the one to make the decision on. In my own view, it should not be a single decision.

Dr. Cogan: I think Ives might have made the same objection to you as you did to Tinker; that it was not done under practical circumstances. Yours was done in a laboratory.

Dr. Blackwell: I am not talking about my data at all. The data I am talking about was done by Weston, Bodmann, Boynton and Boss. What I have done is to put them in a system and they all fit together and concur. It is visibility, the term is performance.

Mr. Crouch: The Ives experiments had some drawbacks because of a lack of knowledge of modifying factors. He did not keep any data on the age of his observers; and, therefore, we do not know what that was. In those days, there were very glaring lighting fixtures and you had disability glare in proportion to the increase in lighting levels which would tend to limit the ability to see. Disability glare is scattered light in the eye media. So, Dr. Ives did not have adequate control. We do not know the modifying factors he had involved in his results.

Dr. Fry: Dr. Grimaldi, you mentioned color in connection with one of your studies on paint, but you did not explain whether the painting was to increase the level of illumination on the task or whether it was color coding, which is widely used in industry.

Dr. Grimaldi: By painting the walls and ceil-

ings, the levels of illumination were increased.

Dr. Fry: Is there any information on color coding and the reduction of accidents. Industrial Engineering in our university places a lot of emphasis on it.

Dr. Grimaldi: Again, this is like illumination. I think that the information that we have is not based upon the kind of scientific investigation that we can put our confidence in. There are a number of pieces that have been written from time to time. The real hard facts are very difficult to discern. I think that anybody who made a recommendation with respect to color coding in terms of absolutes would be on dangerous ground. There is a lot of logic to it, but what it really buys I think is difficult to determine. My answer is, I do not know for sure. During World War II, there was a strong trend towards using color coding. But whether there was any significant result in terms of injury reduction, I do not know. I simply have no scientific evidence of such a relationship.

Mr. Caplan: Dr. Grimaldi, earlier you were talking about the statistics that are available from the National Safety Council, the Industrial Accident Commission, etc. In your terminology, you are using the word "accident." Are you using that synonymously with "injury"? In some cases, you may have an accident with no injury or you may have an accident with multiple injuries. There is a lot of data on injury and how many people have been injured by certain things; but we do not really have very much data on how many accidents have occurred where there have been no injuries, such as, when a box falls down and nobody happens to be under the box. Maybe we should be thinking more in terms of how many untold situations occurred.

Dr. Grimaldi: When I talk about accidents, ordinarily I discriminate between preventable injuries and unpreventable injuries.

Mr. Caplan: They have good accident reporting, for example, in the state of California. When a person reports an injury, when anybody gets a broken hand or something in their eye, or whatever, it has to be reported and there is usually a good write-up on what caused it. But how many times has this accident occurred and was not reported?

Dr. Grimaldi: This is so in a number of states. When you say "good reporting," you mean reporting that is compatible with the requirements for compensating the injured worker. That is

not necessarily good reporting from our point of view. We would like to get definitive information about how the injurious event took place. For example, a good reporter, from the employer's point of view, is one who would provide as little damning information as possible, so that, if the case were to be heard before a referee, the best climate that might be created would occur. Under those circumstances, you do not get definitive information about the event.

Dr. Cohen: I just wanted to tack on a few clarifying comments to those just offered by Mr. Caplan on accident statistics connected with illumination problems. What he said is that the accident information which we have available represents lost-time accidents. At least up until recently, accidents, where only first aid was required, were not reported. Therefore, the twenty percent figure offered by Dr. Grimaldi may really be the tip of an iceberg. I am very much surprised to hear that the illumination has been implicated in as many as twenty percent of the accidents that have been reported because this represents lost-time cases. Cases even involving medical treatment with no lost time would not be listed in that type of total.

Mr. Crouch: Since Tinker's work keeps being revived in literature by those who do not want to use the illumination levels that IERI and IES find, I think we ought to clarify the way Tinker interpreted his material. This was true of earlier investigators, also, like Ferree and Rand. It was not until Lythgoe came along that he pointed out the inherent defect of plotting the data. Lythgoe said so many people are plotting the visual data on arithmetical coordinates, and he said the curve goes up and bends over like this and stretches out here like this and you get no gain beyond this bend point. This is what Tinker used. Lythgoe pointed out the fact that all you were doing was deciding upon the knee of the curve, which is three or thirty or three hundred of an exponential function, depending on the scale. All of our early work by Ferree, and Rand Tinker, and so forth makes this kind of plotting. Now, it was told to Tinker and he said this is so small up here we will just disregard it. So he continued to insist on plotting the material this way. Also, practically all of Tinker's work was on black and white material. His observers were to go through a

SAFETY AND HEALTH EFFECTS OF REDUCED ILLUMINATION

paragraph of printed material as fast as they could, and there were nonsense words every so often to make sure that they were cerebrating instead of just mechanically reading the words. This is the kind of answer he got (three to four footcandles for the knee of the curve). May I say that Blackwell's material has been plotted in relation to Tinker and they agree beautifully for black on white material.

The Hawthorne tests have been so often referred to over the years as evidence against the illumination levels being recommended. The conclusion—"it is merely motivation and not illumination that causes better performance." May I say that in all recent years the work that has been done in industry, as far as the Illuminating Engineering Society is concerned, has been to conduct the tests over a

long period of time. When you once make the change, you conduct it over a three year period of time and see if the motivation irons out. The workers have changed their normal, rhythmic production by an ability to see better. The Metwood Corporation on the west coast was an illustration of this. They had outside auditors come in and check over about a two-year period to see if illumination levels, according to the task needs, would produce, and they did. They went up and maintained continued production for that time.

The Douglas Aircraft Corporation, on miniature electronic components, decreased their rejects. They did not increase their production, they decreased their costly rejects dramatically and they went from four aspirin tablets per person down to zero.

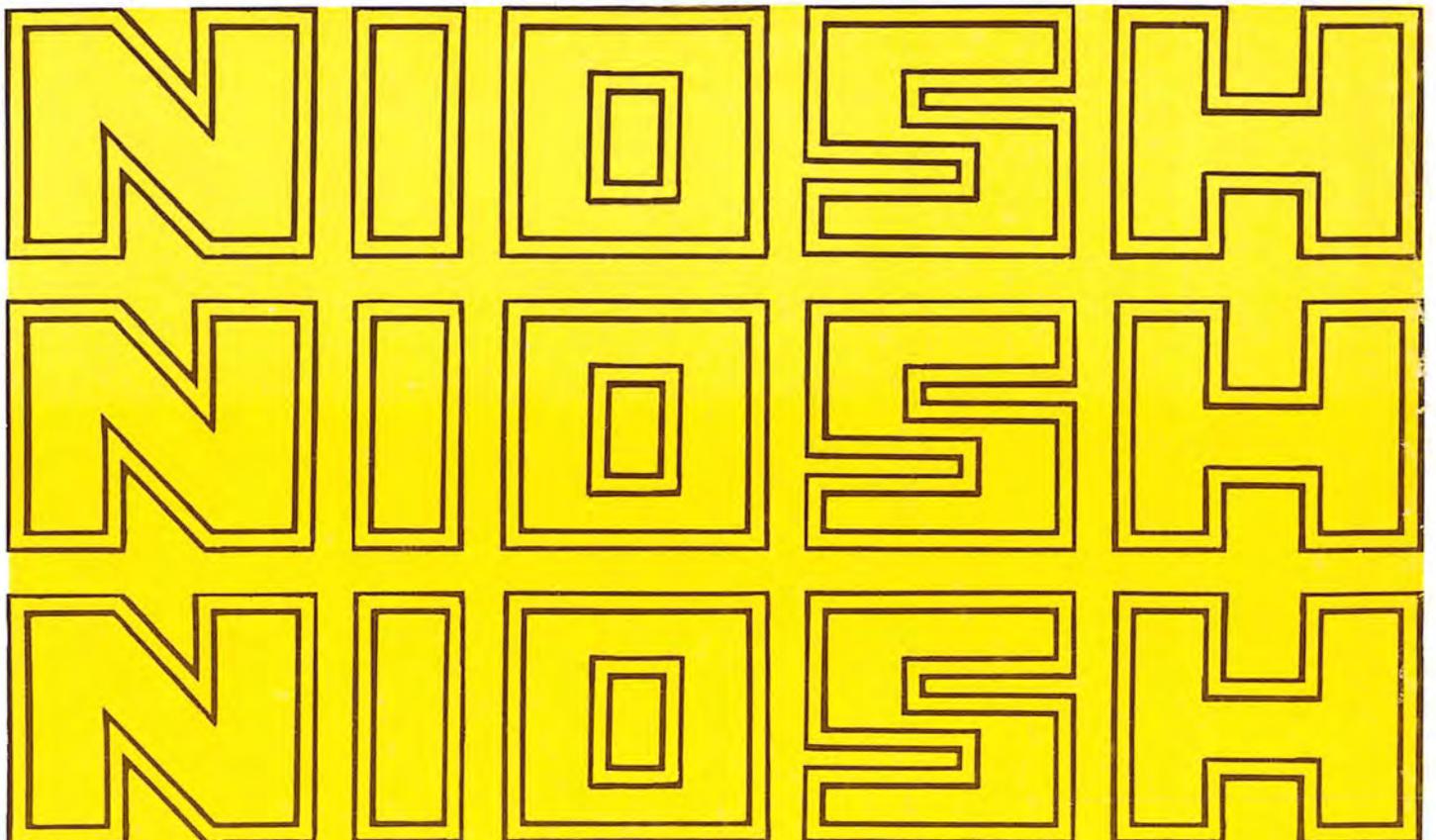
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Symposium Chairman

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