NIOSH

The Occupational Safety and Health Effects Associated with Reduced Levels of Illumination

Proceedings of Symposium

Cincinnati, Ohio

July 11 - 12, 1974

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Allan P. Heins, Ph.D.

Symposium Chairman

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Center for Disease Control
National Institute for Occupational Safety and Health
Division of Laboratories and Criteria Development

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These proceedings were compiled and arranged by Allan P. Heins[1] with the assistance of William E. Murray of the Physical Agents Branch, Division of Laboratories and Criteria Development, NIOSH.

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FOREWORD

The National Institute for Occupational Safety and Health (NIOSH) conducts research, recommends occupational safety and health standards to the Department of Labor, and conducts training and related activities to assure safe and healthful working conditions for every working man and woman in the Nation.

Reduced levels of illumination are currently being used in our country as a method of energy conservation. As a result, many questions have arisen regarding potentially deleterious effects on worker safety and health. The Secretary of Health, Education, and Welfare, Caspar W. Weinberger, requested that NIOSH investigate the potential effects of these reduced levels of illumination on safety and health in the work environment.

NIOSH conducted a symposium on reduced levels of illumination July 11 to 12 in Cincinnati, Ohio. Based on the premise that energy conservation is a long-range goal, knowledge and information pertaining to safety and health effects associated with working under reduced levels of illumination become of prime importance. The purpose of the symposium was to review and discuss potential problems. The primary objectives were to ascertain the current level of knowledge on safety and health associated with low levels of illumination, to identify areas where research is needed, and to create an awareness of these areas so that future research efforts can be appropriately directed.

The information contained in these symposium proceedings should be of interest and assistance to public and private institutions and organizations, as well as individuals who have an interest in the relationship of illumination to safety and health.

Edward J. Baier
Acting Director,
National Institute for
Occupational Safety and Health

PREFACE

The reduction of illumination levels in the workplace, as a means of conserving energy, is currently being carried out in Federal facilities and is being recommended to private industry. Questions, however, are being asked concerning the possible occurrence of adverse safety and health effects resulting from reduced illumination levels. As a result, the National Institute for Occupational Safety and Health sponsored a symposium to discuss this potential problem.

It was decided that the objectives of this symposium could best, and most efficiently, be accomplished by the assembly and interaction of a small group of selected experts, familiar with the various aspects of this topic. No attempt was made to invite everyone knowledgeable in the field of illumination. The persons attending the symposium are imminently qualified in this area and NIOSH is grateful and appreciative for their participation.

The majority of the information available from past research in the illumination field has emphasized visual performance. Safety and health have seldom been considered in recommending illumination levels. In this symposium, an attempt was made to focus primarily on safety and health while de-emphasizing visual performance. The short-term effects of working under reduced illumination levels, such as the potential for accidents and eyestrain were considered. Also discussed were possible subtle, long-term effects.

Regarding the general format of the symposium, all participants were requested to provide a twenty-minute presentation in their area of expertise. Time was provided for discussion immediately following each presentation and, after the formal program was completed, the floor was opened for a period of general discussion. Presentations and discussions were recorded and transcribed by a court stenographer. A draft copy was then forwarded to each participant to edit his presentation and discussion prior to publication. Minimal editing of the final version of the proceedings was provided by NIOSH in an attempt both to expedite the public dissemination of this information and to preserve the informal language which prevailed during the conference. Some of the slides discussed were not available for incorporation in the proceedings. Administrative announcements, "asides", and incomplete or repetitious comments were deleted. For any errors which occurred during the compiling of these proceedings, we apologize.

Finally, we recognized that quite often, subsequent to participation in a symposium of this nature, participants may have additional comments which they would like to make. Consequently, each participant was given the opportunity to provide post-symposium statements or comments for inclusion in these proceedings.

Sincere appreciation is expressed to the NIOSH attendees for their participation and assistance in reviewing the NIOSH post symposium comments. Special acknowledgment is also made to Dr. Wordie Parr, Chief, Physical Agents Branch for his invaluable guidance in this endeavor.

Allan P. Heins, Ph.D.
Symposium Chairman

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OPENING REMARKS

William D. Kelley

Chairman Heins: I would like to bring the meeting to order, please. As Symposium Chairman, I would like to welcome you to Cincinnati on behalf of the National Institute for Occupational Safety and Health. We certainly appreciate your taking time from your busy schedules to attend and participate in our symposium. As our first order of business, I would like to introduce Mr. William D. Kelley. Bill is the Assistant Director for the Division of Laboratories and Criteria Development and is going to provide a few opening remarks.

Mr. Kelley: Thank you, Al. Good morning, ladies and gentlemen. As Al indicated, my name is Bill Kelley, and those of you who have known me for awhile, including Dr. Grimaldi, realize that I am originally from the Division of Training of NIOSH. That is why Al has not turned on the PA system, because he knows, being an old trainer, the system would be drowned out. Seriously, I would like, on behalf of Dr. Key, the Director of NIOSH, and Dr. Fairchild, Associate Director of NIOSH for Cincinnati Operations, to welcome all of you to Cincinnati for this symposium.

If I may, I would like to take just a few minutes to give you a brief outline of the National Institute for Occupational Safety and Health and some of its functions and responsibilities, particularly in this area. As you are undoubtedly aware, our Institute is headquartered in Rockville, Maryland, a Washington suburb. Dr. Key and his administrative staff and several of our functioning offices are located there, including the Office of Research and Standards Development, known for the criteria documents which have become certainly one of the trademarks of NIOSH over the last several years.

Cincinnati houses the principal research facilities for NIOSH. The Division of Laboratories and Criteria Development is located at 1014 Broadway, the address traditionally associated with NIOSH in Cincinnati. The Physical Agents Branch, of which our Chairman is a member, is one of several Branches located at this address. The Division of Field Studies and Clinical Investigations, the Division of Technical Services and the Office of the Associate Director for Cincinnati Operations are located in the Post Office and Courthouse complex. The Division of Training, our meeting place for this symposium, is one of the divisions here in the Federal Office Building.

The Division of Laboratories and Criteria Development is composed of some six branches and provides laboratory research facilities for almost all of NIOSH's responsibilities across the board. The Physical Agents Branch, under the direction of Dr. Wordie Parr, has responsibilities principally in the area of noise and in ionizing and nonionizing radiation. The subject of illumination obviously fits into this overall responsibility.

The Physiology and Ergonomics Branch, under Dr. Frank Dukes-Dobos, has been principally concerned with heat stress, indicators of strain, and other physiological, ergonomical, and biochemical aspects. In addition, research in a relatively new field for us, that of chronic vibration, both full-body and segmental, is being conducted by this group.

The Behavioral and Motivational Factors Branch, under the direction of Dr. Alex Cohen, has responsibilities in two specific areas: behavioral toxicology and psychological motivational aspects, particularly as related to worker safety, psychological strategies and successful versus not-so-successful safety programs.

The Toxicology Branch, under the direction of Dr. Herb Stokinger, is one of our horizontally organized branches primarily involved in chronic inhalation toxicological studies plus some acute and subacute studies for a whole host of substances found in the working environment. Much of their work over the years has provided some of the basic documentation for establishing occupational exposure guides which have historically been used voluntarily, but, now perhaps, on a regulatory basis.

The Engineering Branch, under Mr. John Talty, provides sampling methodology for both gases and vapors and particulate materials in the work environment, covering everything from vinyl chloride to mercury to cotton dust and most other things in between. Control technology projects are being carried out emphasizing ventilation for the recirculation and conditioning of air, an important topic in terms of energy conservation. Also, the Engineering Branch has responsibility for personal protective devices starting out with respirators and moving on into other personal protective equipment types. The Branch also has a small research effort in the safety engineering area.

The Physical and Chemical Analysis Branch, under Mr. John Crable, is responsible for the analytical portion of sampling and analytical methodology in conjunction with the Engineering Branch for the various contaminants in the workplace. These activities, of course, are supported by several other support units; our Statistical Services Group, a Chemical Reference Laboratory which assists in the improvement and validation of routine industrial hygiene analytical work, and the Testing and Certification Laboratory at Morgantown, West Virginia, which shortly will become a division in itself. The Morgantown facility also houses the Appalachian Laboratory for Occupational Respiratory Diseases (ALFORD) which conducts coal mine health research.

NIOSH also maintains the Western Area Occupational Health Laboratory (WAOHL) in Salt Lake City, Utah. The Laboratory is responsible for development of a viable agricultural safety and health program, exploration of NIOSH's role in mining (excluding coal mining) safety and health, and routine analytical chemistry services.

That is a rundown on the NIOSH organizational structure which perhaps, will give you a feel for the context within which the Physical Agents Branch operates in general and its interest and aspects in relation to the illumination area. Thank you.

THE FEDERAL ENERGY ADMINISTRATION'S LIGHTING ENERGY CONSERVATION PROGRAM

Kurt Riegel, Ph.D.

Dr. Riegel: I am very happy to be here today to tell you something of the Federal Energy Administration (FEA) program in lighting energy conservation and to learn from you about the main subject of the conference, i.e., health and safety effects due to low lighting levels that may result from our national energy conservation goals.

Let me begin today with a discussion of the FEA, and my office in particular, with some of the background on what we have done. Then I will move into a discussion of what we intend to do in the near future. The FEA has the primary responsibility for actions in the energy field, including both demand and supply considerations and their national policy ramifications. Up to now, we have not been so much concerned with hardware development as with taking those steps which will result in a coherent national policy with respect to both supply and demand. We take the point of view that demand considerations are just as important as supply considerations and this has led us to this very strong energy conservation effort. The Administrator of the Federal Energy Administration is John Sawhill. (Mr. Sawhill has since resigned.) There are a number of Assistant Administrators; for example, Roger Sant, Assistant Administrator for Energy Conservation and Environment, whom I work for. My work is in research and development in buildings energy conservation. Other conservation activities are those relating to transportation, industrial processes, utilities, and others.

Our programs in the Buildings Branch of the Office of Energy Conservation and Environment have national policy implications. One that occupies our attention is setting the course for research in energy conservation and lighting.

We do take the point of view that lighting is very important in national energy conservation programs for two reasons. First, lighting, both indoor and outdoor, represents a large and significant energy use. It is highly conspicuous because one of our senses responds to the use of energy in this form. And, secondly, we believe that opportunities for energy savings in lighting are quite large. Of all areas one can think of, this area is particularly vulnerable because lighting energy is often used quite wastefully. We find there are quite large opportunities to conserve it, and those are the ones we want to address ourselves to.

As recently as only a few years ago, lighting estimates ran as low as about one percent of the total national energy consumption. We have found this is a gross underestimate, and our best present data indicate that the proportion of national energy which goes into lighting is probably on the order of about five percent, more than five times as large as estimates you were seeing a few years ago. This estimate comes from a report of the Rand Corporation done several months ago, sponsored by our office, and is based on manufacturer's statistics for lamps and other lighting equipment. There is little direct information on how much energy goes into lighting; but one can get a handle on the consumption of energy for lighting purposes by looking at manufacturers' data on lighting equipment, and by making assumptions about the rate of replacement and the rate of installation in new facilities, thereby arrive at an estimate which is in the four to five percent range.

There are two other reasons for emphasizing the importance of lighting in energy conservation. The first is that the five percent figure, in fact, is an underestimate because it only takes into account those direct uses of energy for lighting—the electricity which actually powers lamps. There are indirect effects of lighting which we are beginning to realize are quite important indeed. Particularly in large, commercial buildings, such as office buildings, one finds the installed lighting can dominate the energy requirements of a building. Enough waste heat is generated from installed lighting that the major energy load of the building is accounted for by lights and by the air conditioning systems needed to remove heat from installed lighting systems. We feel that the five percent figure, in fact, grows to about six percent when those indirect energy requirements are taken into account.

For an office building in Los Angeles, another Rand study showed that the direct use of energy amounted to 153,000 BTU's per square foot per year. Heating requirements were quite low because Los Angeles has a rather mild climate. The cooling requirements were higher, mostly due to installed lighting. If one adds the cooling and heating requirements, one finds that well over fifty percent of the total energy requirements of that building are accounted for by the installed lighting. Now, if that building is operated on a twenty-four-hour schedule, the situation becomes even worse and the cooling load climbs dramatically. If one delamps or, by some other means, reduces the energy devoted to lighting, this can be reduced to roughly one-half. Both the direct and indirect energy requirements drop and one obtains substantial energy conservation, both with respect to the normal schedule and a twenty-four-hour lighting schedule.

You might think this kind of example is not typical of the country because the building is located in Los Angeles. As a matter of fact, we find that, for a typical large office building, it is those cooling loads which consume the most energy across the nation. Many large office buildings are being cooled all the time, even in the middle of winter. We have examples of buildings which, even down to zero degrees, require cooling because of internal loads, primarily lighting.

A second reason for emphasizing the importance of lighting energy conservation is that lighting energy is of a particularly critical type, namely, electricity. This end-use energy form is interesting to us for a number of reasons. There are a number of special problems associated with it, problems of great public concern. All of us are aware of the environmental problems associated with the production and distribution of electricity and of the peak-load problem. The use of electricity varies quite strikingly during the day as well as seasonally and one finds that there are a number of social and economic problems associated with fluctuations in electricity usage. There are large requirements for capital investment in equipment to handle peaks. Peaking equipment is generally less efficient than the equipment which is used to handle the base load of the electric utilities. To the extent that those peaks are filled in by less efficient generating devices, we are concerned in the Office of Energy Conservation about reducing such peak demands. The worst peaking problems, in fact, are due to air conditioning and we have already seen that installed lighting is a critical determinant in the air conditioning load for a building. We think we can make a contribution to the peaking problem by concentrating on energy conservation opportunities in operation of lighting systems.

Looking at the manufacturers' statistics for lighting equipment, we find that about 330 billion kilowatt hours per year are devoted to illumination in this country. As a percentage of all forms of energy, it works out to about five percent. As a percentage of electricity, however, this becomes, not five percent, but twenty percent.

The Rand Corporation also offered a number of conservation suggestions and estimated the potential energy reduction for each. The list of suggestions for reducing lighting energy requirements could add up to something like 800,000 barrels of oil per day, equivalent in energy, if all of these measures were adopted. Roughly then, something on the order of a million barrels of oil equivalent per day is a target that we might hope to shoot for in lighting conservation. That is a significant energy target and that is why we have settled on this problem as one that is worth some effort and some expenditure of funds.

I will now give you a little history on the FEA's activities in lighting. Last winter, at the height of the energy shortage, several different approaches were considered by our Agency and with other agencies like the General Services Administration (GSA) and the National Bureau of Standards. First, we considered a straight percentage reduction in lighting levels.

It was quickly apparent that this was not a particularly intelligent way to go because there is an enormous variation in the way people use light. Some users are already quite good citizens; others use lighting quite wastefully. It would not make a great deal of sense to apply a straight, across-the-board reduction factor to all users regardless of their past experience.

Another approach that was considered was prescribing a kind of energy budget for lighting expressed in units of watts per square foot or something of that sort. But we find that this is not a particularly good way to go at present because of a number of complications associated with that approach. There are factors of installed-lamp efficiency not taken into account if one works purely in energy units. Although energy consumption is what we are really interested in reducing, casting standards in terms of energy units, may cause problems because there are wide variations in lamp and luminaire efficiency. There are also quite striking variations in lighting requirements depending upon the task to be performed. It was felt that specifying energy per unit area did not have the flexibility we needed in covering both high and low lighting requirement situations and illumination levels were more widely understood than power densities.

The approach that was finally settled on was to prescribe guidelines for illumination expressed in lumens per square foot. There were two reasons for this. One was that, generally, we felt that installed levels of lighting were often higher than necessary and that the Illuminating Engineering Society (IES) recommendations on which actual installation is based were unrealistically high. Numbers that have appeared in the literature in the past as recommended levels have become minimum levels in practice. It is not terribly uncommon to find installed lighting of 250 footcandles in general office areas which seems to be quite ridiculous.

We arrived at the 50/30/10 standard with GSA and participated with GSA in publicizing it and seeing that it was implemented in government buildings. The 50/30/10 standard is 50 footcandles at the working area (on the desk top), 30 footcandles in general office areas, and 10 footcandles in hallways, corridors and other seldom occupied areas. The recommendations also included the desirability of nonuniform lighting. It is not necessary to prescribe uniform illumination over very large areas if most of those areas are unoccupied. We wanted to start people thinking in terms of directing light only where it is really needed, where people work and at levels which are appropriate to the tasks people are doing.

The other hallmark that we wanted to emphasize was flexibility and control. There has been a cookbook kind of approach in the past, where large areas were bathed in uniform levels of light. We wanted to get across the point that flexibility in directing light where it is needed, and control of its use during the day, are both desirable objectives. We intend to continue with a purely voluntary kind of approach. There are only two exceptions where we feel that something like the force of law or mandatory requirements may be applicable. One is already in operation, and that is the Federal Energy Management Program. The government is able to control the use of energy quite well in the facilities which it owns and operates. We have implemented the 50/30/10 standard for an indefinite period. The other possibility for mandatory requirements would be in the area of contractor compliance. We are considering, and there may be published in the next few months or so, proposals for requiring that major government contractors comply with the same illumination standards that the government itself has adopted. But the main thrust of the program is purely voluntary and we intend to follow this indefinitely. We feel that there is a substantial, and growing, body of opinion that is in harmony with the idea there are enormous opportunities for energy conservation which serve not only the national interest but also the interest of the people who use lighting energy. That is the message we want to try to deliver.

I want to tell you about a new draft of our lighting guidelines, which really only amounts to a revision of things many of you have seen before. I brought a copy of these guidelines to distribute today. (Appendix A.) I hope you will look at these and I will be very happy to get from you any comments or suggestions which we can incorporate before actual publication.

Another approach that we followed, besides simply prescribing light levels, is that of encouraging people to convert to more efficient light sources where possible. Where you have incandescent, convert to fluorescent, where you have fluorescent in large areas, consider the use of high-pressure sodium vapor lamps, mercury vapor lamps, or other types of more efficient light sources.

For the coming six months to a year, we have a number of research activities planned in the area of energy conservation and lighting. I would like to tell you about one contract we just signed with Ross and Baruzzini of St. Louis. This firm did a study for GSA on lighting energy conservation in buildings. We find that was an excellent initial study but there are a number of areas we would like to proceed further into. This study that they will be doing centers on the following three areas.

First of all, we want to try to pin down more accurately the actual energy consumption due to lighting in office buildings in this country. For reasons I have already given, we feel that office buildings represent a particularly good target for lighting energy conservation because the installed lighting represents a major fraction of the total energy requirements, as much as eighty percent. Rather than relying on the manufacturers' data for lighting equipment, we would like to rely more on actual measurements of installed-lighting energy consumption—this is one of the things we hope to accomplish.

The second area would be an analysis of human lighting needs in office situations. What is really required for the kinds of tasks typically performed in an office situation? Much of the research done in the past has been idealized, as much research needs to be, in order to make it a tractable undertaking. We would like to push research which is very closely connected with "real world" tasks done in typical office situations. With this information, we can establish realistic minimum illumination levels —which are sensitive to energy conservation goals.

Finally, we are sponsoring research which will lead to recommendations for standards development and the formulation of policy alternatives which speak directly to the goals of energy conservation in office buildings. Our objectives will continue to encourage energy conservation in lighting wherever possible. We want to consider performance and safety and health requirements as well, and so I am very happy to have an opportunity to sit here with you in this symposium during the next two days. We recognize the importance of looking into these matters, and of being very careful that the recommendations that the FEA or the GSA makes are not contrary to health and safety requirements. We look forward to learning a great deal from you about this field.

Thank you.

DISCUSSION

Dr. Blackwell: I want to make a respectful comment to Dr. Riegel. He used the words "wasteful" and "unnecessary" repeatedly in referring to light levels. I hope we will persuade him to keep an open mind until he listens to what we have to say before he makes up his mind. At some point, I will ask him his age, because that is going to be quite relevant to his own personal interpretations of the words. I was a little shook up that you feel you could use words like "wasteful" light and "unnecessary" light at this point. I think we are here to talk about whether or not those words should be used.

Dr. Riegel: I think there are situations where all of us could agree that the word "wasteful" is entirely appropriate—such as unoccupied office buildings illuminated at high levels all night long. I also feel that levels are often higher than necessary in many office buildings. It is not only illumination levels that are important, but also, the operation of these buildings and the schedule of daily activities. Incidentally, I am 35 years old.

Mr. Nelson: May I make a recommendation? If there could be a stipulation that we will not use the words "wasteful," "excess," "hazardous," or "harmful," we will not use the key catchwords of either side of this question. If all sides will agree, we will not use "hazardous," or "unsafe," but rather that we will talk about ability to see. And we will not use "wasteful," but we will talk about energy use. If we can stipulate on those two, I think the communication level will be a lot better.

Dr. Halldane: To summarize this, superlatives should be avoided.

THE GENERAL SERVICES ADMINISTRATION'S APPROACH TO ENERGY CONSERVATION IN LIGHTING

Harold Nelson

Mr. Nelson: The General Services Administration, as the basic building construction and operating agency of the Federal Government, has both extensive experience and a wide range of responsibilities. It has always tried to balance employee comfort and efficiency with the judicial expenditure of Federal funds. While meeting the safety and health needs has always been an important part of the GSA objectives, GSA has recently emphasized and amplified its commitment to safety in new policy statements and statements and actions of its top officials. We also are just as firmly committed to a policy of not only positive action in conserving energy but also to a position of conserving the Nation's energy resources. Our actions have already demonstrated that sizeable energy conservation is achievable. We are determined to be successful in making additional significant reductions in energy utilization in Federal buildings. We recognize that what we do may well become models for others. We are convinced that energy conservation is necessary, practical, and compatible with the overall objectives of GSA and of the Nation, including safety and health. Such a totally balanced goal is possible only if reasonable men work together and determine or develop the valid data in useable form that will permit sound judgments based on the best facts and measurements possible. Any case, where hard questions have been sidestepped by conservation overdesign at the cost of energy, must be attacked. In the forthcoming arena of competition for limited energy, energy using needs, such as illumination, are going to be pressed to justify their case. It is important that meetings such as this take the problem head on. Since the relationship of illumination to energy is quite direct while the connection between safety and health and illumination is difficult to specifically quantify, safety will be the loser unless these needs can be well defined and supported.

BACKGROUND

In the 1930's, lighting in Federal Buildings was provided by incandescent lamps in the 15 footcandles range. Additional task lighting needs were provided by exterior lighting through windows and desk lamps. In the 1940's, the fluorescent lamp was introduced and lighting levels were increased to about the 30 footcandles range. As late as 1967, GSA design standards called for 35 footcandles for general office lighting and 50 footcandles for prolonged close work and difficult seeing tasks.

In the early 1960's, the modular design concept was adopted where entire floors of buildings were designed to have the same lighting level (50 footcandles). This uniformity provided maximum furniture placement flexibility without regard to ceiling fixtures. While our standards provided for 2 levels of light, most designers provided fixtures in all space capable of lighting to the higher, rather than the lower level.

In 1967, GSA adopted higher levels for general office and difficult seeing tasks when it raised levels to 75 footcandles. A level of 30 footcandles was specified for ordinary and intermittent seeing tasks. In effect, this raised all lighting levels in new buildings to 75 footcandles as lighting was designed for maximum tenant flexibility. Thus, people became accustomed to working in the higher intensity lighting levels. In an effort to simplify instructions to Contract Architects and Engineers, GSA published a condensed handbook for design of new buildings. The handbook accepted the Illuminating Engineering Society standards as a basis for design in December 1972. In January 1973, Integrated Ceiling Standards were issued by GSA for modular design at 60 footcandles for general office lighting on the task.

While our new construction design standard prior to the energy crisis was 75 footcandles, our guidelines for existing building remodeling allows for 50 footcandles of lighting. It is interesting to note that although we have numerous buildings where the predominant lighting level was in the 50 footcandles range prior to the energy crisis, we have no record of visual problems at these locations. It is understandable that employees accustomed to brightly lighted offices will psychologically react to the lower lighting levels and question the wisdom of the GSA's action.

In May 1972, GSA cosponsored with the National Bureau of Standards an Energy Roundtable of outstanding designers, and executive and Government officials with responsibilities in all phases of building construction, design and management. On Standard Levels of Illumination the report stated:

> The lighting standards used in new buildings should be carefully reviewed. In many cases, we may be lighting work areas at levels five or six times what is actually necessary. Reductions can be made without jeopardizing hygienically and psychologically adequate illumination levels, while realizing considerable savings. By halving an illumination level, the energy requirement is cut by significantly more than 50 percent. For example, when artificial illumination is reduced from 150 to 50 footcandles, the energy required drops by over 90 percent.

In recognition of the roundtable evaluation, GSA initiated a comprehensive lighting study by the engineering firm of Ross and Baruzzini in January of 1973. In the view of the critical energy situation and the need for the Federal Government to take a leading role in the conservation program, the General Services Administration, in coordination with the Federal Energy Administration, established regulations for lighting intensities in Government-owned and -leased buildings which were published in the Federal Management Circular, FMC 74–1, January 21, 1974, addressed to the Heads of Executive Departments and Establishments. The regulations provide for lighting intensities of 50 footcandles at work stations, 30 footcandles in work areas, and 10 footcandles in nonworking areas during working hours. A safety minimum of 1 footcandle was set for the inevitable shadowed areas in corridors and walk ways.

These regulations were based upon performance engineering considerations and were used in space utilized for general office type activities. Provisions for exceptions to the standards for higher levels of lighting for specialized tasks are included in the Circular. These regulations reflect the recommendations of the engineering study.

Some of our occupants, through representatives of their employee organizations, have expressed concern that these levels of lighting may cause eye fatigue, eye damage, headaches, etc. Most, if not all of these fears, are based on the reduction from the higher lighting levels recommended by the Illuminating Engineering Society (IES), and have been followed for a number of years by both private and Government agencies. The IES recommended levels were based on a 99 percent accuracy of performance developed during periods of energy abundance. We believe, however, that during the current situation, we must be able to distinguish between that which is desirable and that which is required.

FUTURE

The future designer will no longer be able to design on the basis of total space lighting at levels sufficient for the most difficult tasks and for most poorly sighted workers. He is going to have to execute an energy conserving system with the minimum of energy expended on nonwork areas, and the specifically needed illumination at the actual work place. He is going to be subjected to simultaneous demands for sufficiency and conservation. To do his job, he is going to need more and better data on the effect of illumination and other vision affecting factors on the total man.

CONCLUSIONS

In order to move forward with conservation in consort with safety and health, and, with measured regard for comfort and efficiency, it is urgently requested that this meeting either develop or start in motion the action that will lead to the development of all the parameters governing the impact of illumination on safety and health. We not only need to know the parameters, but also the degree or extent of impact resulting from various graduated changes in the related variables. We must go beyond standardized go/no-go criteria and progress to evaluate the impact. We doubt that we have recognized specific needs that demand attention now. These include the physiological effects of low levels of illumination at the work place; the levels of illumination required by both normal and impaired vision persons to see physical hazards in the work areas or passages; and, the impact of surroundings, color, or contrast on health or safety. We also need to know how to specify, if other than footcandles, in a manner compatible for convenient measurement. We need to know the adequacy of measurement equipment as it relates to the physical characteristics of the eyes. If current data is not adequate, we need to have identified areas of further research.

Note: The following material was provided to each participant by FEA and GSA:

1. Lighting Systems Study, Ross and Baruzzini, March 1974.
2. Federal Management Circular 74–1: Federal Energy Conservation and supplement.
3. Energy Roundtable Report on Energy Conservation in Public Buildings.
4. Memorandum dated March 29, 1974, from the Assistant Commissioner for Buildings Management, General Services Administration to all Regional Commissioners, PBS on Safety and Energy Conservation.

DISCUSSION

Dr. Halldane: I would like to respond to one thing you brought up very quickly—the problem of instrumentation. Later on, I will bring out the business that the light meter is not the only instrument we have to deal with; and that, fundamentally, most of the visual responses will be responding to such things as measurements with a telephotometer, which is a much more expensive instrument and relates more to the visual response than does the illuminance measured by an incident photometer that we are going to deal with. And we have also got to come to grips with calibration, which tends in some cases to be more expensive than just buying the instrument itself, particularly when you get to telephotometers and other standard sources. Your point is very valid. You will have to consider the economics of instrumentation, of monitoring whatever comes up, and I would like to address this later on this afternoon.

Mr. Nelson: I have found in my work that there are three levels of sophistication, and most of you are in top-level sophistication. I find, in fire phenomenology, and I believe it is the same here, that the Ph.D., and I suppose the M.D. level, work in complex functions, or, in the doctor's relationship, in long words which carry large meanings and are very erudite and specific and can, shall we say, make flat lines engineeringwise out of some very wriggled curves. But the next move down is the engineer, the B.S. graduate. The most complex function he normally handles is a Reynolds number, because he spent half of his hydraulic engineering course in learning what a Reynolds number is. He is much more tuned to physical phenomena which he can measure with an instrument or a device—mass, speed, weight, heat, illumination. The final level is the technician. He is not incompetent, but he does not know $F = MA$, he does not know $E = IR$. He knows that this instrument and this table go together and he knows that you had better wire black to black, which the Ph.D. may not, or you will blow the damn thing.

Dr. Halldane: I think we have to accept that if you are going to use a light meter, to be of any significance, it has to be photopically corrected and cosine-corrected, too.

Mr. Nelson: All I am trying to say is I would like to have a direct train between the three levels. And one of our problems is that sometimes we do it sophisticatedly at the research level and we do not try to connect it to the man at the bottom. He is going to make measurements somehow.

Mr. Talty (NIOSH): You mentioned something in your circular about heat-of-light technology.

Is that synonymous with the energy budget approach?

Mr. Nelson: In a way, it is probably multipurpose and vague because its answer is vague. Basically, it is the fact that we are getting quite a number of buildings in which there is no heating equipment, and in which we are depending upon the overheat from the ballasts to maintain the winter temperatures. And some of these buildings, of course, in freezing weather, you have to keep the lights on or you have to do something else. Sometimes reheat coils are used. We get all sorts of things. This, again, was a typical sort of thing for a builder to build when the leaseholder was going to pay the electric bill.

Mr. Talty: That leads me to another question. Dr. Riegel, from the FEA mentioned that the energy budget approach had been considered and dropped because there were too many unknowns. I am wondering, if that is an adequate basis for dropping it?

Mr. Nelson: Well, the GSA is doing a kind of energy budgeting and I am going to digress now into total energy. We in the federal government can serve as a model. Also, because we are code-exempt, uninsured and responsible, we can do certain types of modeling for the rest of the world to look at. The Manchester, New Hampshire Building, which is just now going under contract for the GSA, is specifically an energy-budgeted building balance. We have also started including energy direction in our contracts with architects and engineers. We have always given them a space requirement, a real property requirement and a financial budget, plus all the other safety mandates and the other things; but basically those three budgets. We are now giving them an energy budget. I do not know exactly how it is expressed, BTU per square foot, or something like that. We are giving him an energy budget and, frankly, challenging him against the energy budget for his design. This is another model to try. If it works, and it seems to be working in some areas, fine. The question is: What does he sell short to do it?

Mr. Caplan (NIOSH): Is that a variable energy budget?

Mr. Nelson: Oh, obviously it has to be. It has to be related against degree days on both sides of the picture and the designer has to have some sort of balance. I am not completely familiar, but the energy budget, I believe, is established for the architect in a negotiation consultation with considerations of the atmospheric conditions. It will probably be subject to change, because we all know that any weather bureau map shows you geographic norms and can leave you way out for some particular snow belt, wind path or something like that. All you have to do is go up to the Federal Building in Cleveland to see a building in a wind tunnel. This can happen.

Dr. Blackwell: To show that there is communication possible between the different sides of the table, let me say that I, as a vision researcher, feel that we have the know-how to assist you very much in setting criteria in energy terms for different kinds of human performance. I feel, also, that the work we have done, as spun off in the CIE report, makes it possible to evaluate the extent to which different environments, physically produced in different ways, provide levels of visual benefit which can be used as criteria. In short, I believe the basis exists for a reasonable technology now. There is no reason to wait. And I think if we can get on to a discussion of some of these things, this can begin to become apparent. I, myself, do not fight at all the idea of an energy budget. I think it would be very interesting to relate it to human activity. Then, let us see what engineering can do to provide this most efficiently. I do not agree with the notion that, because different light sources are different in efficiency, one should go away from that. All the more reason, if someone can produce a good visual environment with a sufficient light source, why not reward him for it? That is the American way. So let us get visual criteria, and not forget those the rest of today and tomorrow.

Dr. Riegel: I think I agree with everything Mr. Nelson said. I think it is possible we were talking about two slightly different situations. The problem facing the FEA, and the one that I was talking about a few minutes ago, was one of doing something last winter to achieve energy savings in lighting. It was our feeling at that time that it was not a good approach to think of going into existing buildings to use the energy budget approach. I feel that it is a very fruitful area to continue to explore, especially for new buildings.

Dr. Yonemura: I think we should distinguish between energy and power budget. Mr. Nelson used BTU per square feet, and this is a power budget. This is the power required. He also used total energy. I think we should agree, because Dr. Blackwell made the comment about how he can help in the energy budget. I think he meant power budget, because energy very strongly brings in individual behavior, for example, how often he turns the light off and on. This would be the total energy used in a year, rather than the power required, and we should very clearly keep the distinction in mind.

Dr. Halldane: There is a lot of confusion, particularly with the FEA, if you are talking about barrels per day, watts per this and joules per that; and I think everybody here is somewhat confused because most of you have not come through the physical sciences. I have a physical science background, and I am a little more sensitive to this. Now, I think our savior in the future will be through metrication, because this will force us to consider everything in uniform quantities and units. And, when we talk about energy, everything should be talked about and converted into joules. Let us have no mistake about it, it should be, and, then, we will be able to start to communicate with our overseas friends as well as ourselves. I think this is a very significant point. The distinction between power and energy is that power is energy per unit time. Now we know what we are talking about. That has a separate unit, the watt, and it is universal. And the most convenient thing in terms of the watt is of course in electricity. We have various energy and power measures to convert to joules and watts respectively.

I hope to reiterate on this a little more this afternoon; but, as was said in the discussion before, there is a lot of confusion that is developing at this stage. Let us preserve a unification of units and measures and consolidate this as part of our program today.

ILLUMINATION LEVELS IN THE UNITED KINGDOM

R. A. Weale, Ph.D., Sc.D.

Dr. Weale: Mr. Chairman, let me say how pleased I am to be with you on this occasion. Some interesting problems have already come up and I should, of course, be very pleased to hear what other problems come up, even if the price that I have to pay is that I have to do some talking, too. And I realize that this symposium is supposed to be dealing with low levels of illumination; but, for the life of me, I do not know what you mean by "low." When I came in here this morning, I thought that this is intense illumination. I do not suppose that my physiology differs from that of anyone else who is present; it just depends on what you are used to. Then I noticed with horror that half the lights are cut off.

Well, I do not know whether measurement is the answer to everything, as I have just tried to indicate, because you get conditioned even to hell. Light, I think it is pretty obvious to remember, can be used for a number of purposes; survival, work, pleasure—all these have been mentioned; and, do not forget, it is also a commodity to be sold. And this is a problem which I think may affect the three other, what you all might almost call, physiological aspects of either work or pleasure. Work, of course, has tied in with it the question of prestige. The more important office worker has to be better lit, no matter whether the light is needed or not. And, at home, the Illuminating Engineering Society has just produced a new code—I shall tell you about that in a moment—and the code was produced, should I say, under the cloud of the energy crisis. And one or two economic questions have, of course, been asked. It does not follow that just because I mentioned those particular questions they were asked, but it will give you some idea of what you might call the atmosphere in which these questions were asked.

For example, who is going to benefit if it costs more to produce instruments to cut energy, than the energy you are going to save, especially if it is going to cost more in terms of energy to produce those instruments? And the other questions which arise are whether one ought to go hell for leather for outdoor lighting to be imitated indoors. Is daylight lighting a sine qua non, does it have to be produced under all conditions, does it have to be aimed for, is it the sort of thing that is a prize dangled by the gods in front of our eyes?

And the code which is now recommended is not based exclusively on the measurements obtained by either Dr. Blackwell or the late H. C. Weston or anyone else. It partly includes, very largely includes, results of answers obtained to a questionnaire; and, therefore, is based, in part, on user levels. The values which are recommended are certainly not, I repeat, not, minimum values; they are values which are in use in most cases. One asks oneself, of course, whether efficiency is more important than happiness; and, in a problem of this sort, one has to ask oneself whether one should rely entirely on the user. We are all familiar with the driver who feels never happier than if he has had some alcohol. It does not follow that his own response, his own subjective response, is necessarily the best from the point of view of society at large. But we must not forget that, with the exception of—I think I am right in saying—miner's nystagmus, there has been no demonstrable adverse ocular effect due to low illumination. But let me repeat, the sort of situation needed to produce a pathological condition involves illumination levels which are much lower than those you are likely to contemplate in what one can only refer to as reduced circumstances.

We are conscious that reports are coming out that too much light may constitute a health hazard. Experiments have been done—and I am referring only to experiments done on vertebrate eyes—rats, pigeons and other species, chickens, I believe—which show conclusively that what we refer to as normal levels can be harmful. There is no doubt that this unrestricted introduction of daylight everywhere is hampering our enjoyment of, for example, art galleries, where it can be shown that it is quite wrong; but the trouble is that galleries are lit by lighting engineers and not by curators who ought to know better. And, if one takes this aesthetic problem and sets it aside—suffice it that I mention it—we have to ask ourselves to what extent biological mechanisms remember, that is, to what extent any harm that can be obtained, that can be experienced under intense conditions, may perhaps be subject to the reciprocity rule.

Well, these are the sort of questions which we have been asking ourselves; and now, to cut the cackle, let me produce some comparisons between the figures given in this document and the one which I have just mentioned as having been published in 1973. Almost without exception, you will find that the levels recommended in the U.K. are lower than those recommended in this country. And, before I specify this, I am reminded of an interesting comparison which we made some little time ago, for example, between the values recommended in Soviet Russia, in the United Kingdom and the United States. And we find that there is some correlation between the light recommended and the wealth of the country, if I may put it that way. And those of you who have traveled in the poorer parts of the European continent, perhaps in the Balkans, perhaps in some parts of Italy, will know what I mean; light is in some ways what you can afford. What that has to do with physiology, I really cannot see; but this may be due to the fact that I am used to less light.

Now, I have not worked out all the comparisons, partly because ours are given in lux and yours in good old British footcandles, but, by way of comparison, let me pick on a handful of them. For example, in airplane repair service areas, you ask for 100 footcandles and we think that 45 are sufficient. Art galleries: on statues, you would recommend 100 footcandles whereas we think that 28 are ample. In assemblies: rough, easy seeing, 50 as compared with 29; medium seeing problems, 100 in the U.S. as compared with 46. For fine work, you recommend 500 as compared with our 93; and, for extra fine, you recommend 1000 as compared with our 140. Book binding, folding, assembling, pasting, and so on: your 70 against our 46. Cutting, punching, and stitching: just to show that I can be fair, 70 against 70.

I have marked one or two where I am afraid you are being absolutely mean with light. In the printing industries, the font assembly, sorting, you recommend 50 as compared with our 70. And, ladies and gentlemen, in hospital toilets, you recommend 10 as compared to our 14.

Library reading rooms: for the study of notes, 70 as compared with our 46; stacks, 30 in the U.S. as compared to our 14. Now, when it comes to book repair and binding we are neck and neck, 40 versus 46; cataloging 70 versus 46; check-in and check-out desks, 70 versus 46. Machine shops: rough bench and machine work, 50 to 28; fine bench and machine work, fine automatic machines and so on, 500 as against 93.

There are some which we find unmentionable. You recommend 1,000 for a dental chair and we just mark it SL, special lighting. In obstetric work, on the delivery table, you recommend 2,500, we recommend SL. And this applies to a number of cases where your recommendations are in four figures and brings me to the point which I really should have made earlier on. I discussed these and kindred problems with Dr. Hopkinson, who very much regrets that he cannot be here, but since we see eye to eye, I can, in a way, speak for him, and he thinks that this sort of comparison, if it is valid, points to what I think Dr. Riegel referred to as task-operated lighting. Dr. Hopkinson reminded me that he has reminded you and your colleagues that the increase in light has gone far enough and that it might, perhaps, be conveniently reversed, but this should not be at the expense of seeing. It is, as you might guess, at the expense of not seeing, of illuminating areas where nobody does any seeing and that, perhaps, local illumination on the task has a lot to recommend it. Thank you.

DISCUSSION

Mr. Nelson: Are the recommended illumination levels of your society those of a consensus group and on what basis were they formulated?

Dr. Weale: Yes, they represent a consensus group and were based partly on measurement and partly on a questionnaire. Obviously it was a complicated thing, the sort of exercise which you have been recommending, even at the best of times. The subject satisfaction is obviously something that ought to be considered. I am reminded of a symposium which was held in Heidelberg nine years ago on the employment of older workers where one of the speakers pointed out that—I believe in the post, that is right, postal workers had been dissatisfied with the light that was used, and, when these were raised to fifty footcandles, everybody was happy.

Mr. Lee (NIOSH): Dr. Weale, you made the statement that you knew of no adverse affects that have been associated with low levels of illumination. Were you referring solely to pathological findings, or do you include in your definition of "adverse effects" subjective symptomatology, such as, headache and eyestrain?

Dr. Weale: I intended to say pathological effects, permanent damage, and so on. If I did not, I am awfully sorry. Things that you can detect, organic changes.

Mr. Lee: The reason, I bring it up is that this group should confront the issue of what is an "acceptable" physiological effect. We are confronting it all the time in the setting of other occupational health standards. In the setting of such standards, we consider not only pathological, nonreversible effects, but subjective and reversible symptomatology as well. Should we not have an illumination standard which prevents eyestrain and headache?

Dr. Weale: Well, it is not up to me to make this decision. Let me remind you that we suffer stress when we drive and the stress passes; it does not stop us from driving. It seems to me that limited reversible changes have to be accepted in modern life. One would not be responsible for damaging a body permanently, even temporarily, but it seems to me that a little bit of headache will happen to you if you get caught in a traffic jam. Are you going to stop driving? You are going to stop driving if it is going to harm you permanently.

Chairman Heins: Dr. Weale, do you believe people in your country who work under the levels which you just described suffer from eye fatigue, headaches and other symptoms of "eyestrain", as a rule, from working under these levels?

Dr. Weale: I am astonished, Mr. Chairman, that these levels are referred to or implied as being low. No, there is no report of anyone, as far as I know—I mean I have not spoken to fifty million people. There is no complaint anywhere. Much more than this country, we are trade-union ridden; and, it seems to me that if there were any complaint, if any money were to be gotten from working under low-level illuminating conditions we would know about it.

Mr. Caplan (NIOSH): Dr. Weale, you alluded to the fact that in the Soviet Union, or perhaps in the eastern European countries, they had a different set of standards on the average. In the field of toxicology, or particularly the field of industrial toxicology, the levels which are considered to be hazardous or causing certain effects are usually lower in the eastern European countries than they are in western Europe or the United States. And I wonder, in the field of illumination, do they have the same general philosophy, that any behavioral changes are considered to be toxic, at least in the industrial environment? You did not mention what the levels were in general in the Soviet Union. Are they lower, or higher or what?

Dr. Weale: They are lower; but I am afraid I cannot accept the premise made by the last speaker. To give one example, the safety levels for microwave radiation are much lower in the Soviet Union than, for example, they are in this country, and we are not prepared to accept that, just because it is the Soviet Union, it follows that they are less concerned about the safety of their people.

Mr. Caplan: I meant they are more conservative. Their standards of allowable exposure to carbon monoxide, for example, or acetone, are lower, more restricted than those we use in the United States.

Dr. Weale: In lighting, it is the other way around. They think that people can manage with less light than the U.K. or the U.S.A.

believe necessary, at any rate, in some respects.

Dr. Blackwell: Dr. Weale has made the point that it seems as if the amount of light used depends upon the economy. I think we can bring out, when we finally get to it this afternoon, that light is a variable which has a return. One can relate the two—lord knows it is not linear. If you have the right kind of specification of light in terms of CIE units, equivalent luminants or illuminations, raw ones, then there is a progressive increase. It is not linear, lord knows, far from it. Now, if that is true, that if you specify light in the right terms, the more of it you have the better you can perform the visual systems, then is it not perfectly reasonable that rich countries would go higher, figuratively, than poor ones? That does not necessarily mean it is some kind of ridiculousness. It is indeed an interesting statement that this country can afford lower—has been able to afford, in the past, to afford cooler temperatures for air conditioning, let us say, more light, et cetera. This does not mean it is folly. It just means that this is, indeed, a continuous variable with no cutoffs, which it is. If one knows the tradeoff relationship, then one can make a decision. We can afford more light. That day may be past; and, if past, then let us see what the tradeoff curve looks like. We can see what happens if we start moving back down. I do not find that that proves it is a folly. It seems to me that is a reasonable thing in the variable which gives a continuous reward going up monotonically, but slowly, in my opinion.

Dr. Weale: I do not think anyone said that it was folly. I just pointed it out as a fact.

Dr. Halldane: I think I can respond to some other questions I have here in terms of other physiological responses. There was some work done on hyperbilirubinemia, particularly in infants in hospitals, that light was necessary for the development of the blood. The development of bilirubin within the blood is dependent on irradiation of the body. Now, this is a very specific case of infants, and perhaps to hospitals. Years ago the mother was informed to get the baby outside as much as possible and it would develop healthy. Now, I think that this is an important thing, that light is important for that physiological process. So that is one response that you could identify with your concern.

The other is the ultraviolet component and the control of bacteria, in that there are some responses here, mainly control of bacteria. A certain amount is necessary certainly not for visual reasons; but I would like to hear others for that.

Now, in terms of Dr. Weale's comments, I originally come from New Zealand and I have been two and a half years in Australia. Of course, when I was designing, I was going by the Australian Standard, which is a compromise between the British and the American. The Australian Standard was influenced by the increases in American illumination over time, but not completely. It has been gradually rising. We must remember that lighting has increased by the advent of certain technologies. First of all, we had the gas light, then incandescent, and then, the real crucial point was the development of fluorescent lighting where you get twice the light output for the equivalent number of watts. So there is your technological and economic development, which were the crucial points in the changes. Now, we are not going to have that advantage from the intense energy sources, like the sodium vapors, inside buildings, because, you have to diffuse it over a wider area. You are not going to get those developed within buildings. But, the more intense sources will become a more economical means for exterior lighting. So it is very clear that we will have to differentiate in terms of technology of exterior, large-distance types of illumination sources where you can develop the economy in terms of your light sources; but you are not going to develop much more efficient types of luminaires materialwise.

What we can concentrate on is a better distribution of luminaires for the interior situation and developing light for specific behavioral responses, such as, specific tasks and specific responses which I hope to identify more this afternoon. I hope this will support your contention. There certainly have not been complaints over time in terms of people unable to work and that lighting levels have increased because of poorer performance. This has never been the argument in terms of the increase in lighting levels, because people worked satisfactorily in gas light. Indeed, I have developed standards for mine lighting in this country and you are dealing with a pretty black environment there. And, for this reason, I developed a standard based on luminance and not illumination, which I will go into later on and the assumptions behind us and where we should be going in the type of specification in the future. But it will support the comments of Dr. Weale that other countries have gone through this and supports his arguments and questionnaires. The development of lighting has not been in terms of any degradation in performance.

Dr. Mead (IERI): I am reminded of a little anecdote that we are probably all familiar with in the classical Hawthorne experiments where the relay room girls were subjected to changes in illumination. Sometimes the illumination went up, sometimes, down; unbeknownst to them. They merely saw people manipulate the bulbs and, in some instances, a special case, the illumination went down to the level of moonlight with no reduction in the assembly of relays and no complaints on the part of the workers.

Dr. Ross (Ross & Baruzzini Contract): Just one further distinction on Dr. Weale's comments about the disparity between the United States and British standards. British standards, as I understand it, are average, neither maximum nor minimum, but good common practice; whereas the United States' standards are minimum standards.

Mr. Crouch: I wish to correct that. The recommendations are called "minimum on the task at any time." And this has been interpreted as being minimum levels. It merely means a maintenance of the level on the details of the task for visual purposes at all times with maintenance factors included. So it was not intended—that statement was not—in fact, if you will look you will find "current good practice" is the heading. And then the level is specified where you measure it at minimum on the task at any time, which allows for maintenance factors, that is all. It was not intended that you should go much higher—the light-for-heat advocates began to use this very expression to indicate that IES was recommending minimums; and, therefore, it was better to go much higher. In the Chicago area, they added one hundred to one hundred fifty footcandles and this heated the entire building without the use of any other energy. Now, the IES protested any visual basis for this (even though it might be economically feasible and even critical fuel wise) and issued a public statement—a published statement—saying that the recommendations of the Illuminating Engineering Society were based on currently known psychophysical data and relationships. It was the best available information at the time, and it was not to be construed that much higher levels would be much better. We did not know. We did not have the facts.

Dr. Riegel: I just wanted to ask Mr. Crouch if he concurs with the view that these levels, although they were not specified as minimum levels, have become so in practice.

Mr. Crouch: Yes and no. While IES issued a public statement and published it in its journal and advocated that all its members follow these recommendations, in every community there is a range of values used by engineers and architects, some of whom go below the standards and some above the standards, but IES has adhered to its recommendations.

Dr. Halldane: The Australian Standard states it is the minimum service value of illumination which gets around the problem of maintenance. We have to get some international terminology and update the IES handbook.

THE ILLUMINATING ENGINEERING RESEARCH INSTITUTE AND ILLUMINATION LEVELS CURRENTLY BEING RECOMMENDED IN THE UNITED STATES

C. L. Crouch

Mr. Crouch: I am very happy for this conference because we are all products of each one of our experiences and if we are true to our experiences we will reflect our current state of knowledge and viewpoint. It is very helpful, of course, to have other viewpoints presented so that we can think in terms of the overall scene and make some adjustments. I must say that I think that all of the people I work with in the Illuminating Engineering Research Institute and, then, through the Illuminating Engineering Society, which uses some of our results, not all of them, we are earnestly trying to conserve on energy. We may differ on philosophy as to how to do it and I think that is where our differences with the FEA occur. We believe that large savings can be shown. May I say that the Illuminating Engineering Research Institute that I represent has recently brought out a folder, which has only come out within the last two weeks, which is called "Effective Seeing and Conservation, Too." We demonstrated in an actual office how we were able to save one-third of the wattage that was put in by architects and engineers under the module plan because they knew nothing about what would be in this building. It was a broad, open space. It ran a block long and a block wide. So they put in high-level, module lighting. So, when the partitions came in and the visual work layout was known, it was easy to reduce and conserve in that situation.

I do not wish to blame the original engineer and architect. They knew nothing about the work layout—and I am afraid this is going to be so for the future—that many times they will not know. As far as my own discussion is concerned, I try to say "Put in a great flexibility of switching arrangement." I am advocating that the architect or engineer, primarily the engineer, go back six months after the building is completed and then arrange the lighting through switching according to the work that is being carried on, the visual work. We think that this is truly the functional way, because it is almost impossible for the architect and engineer to know, in most buildings, what is going to happen.

By the way, Mr. Nelson, I am glad to meet you. I have had some conversation over the phone. I hasten to indicate, and I think it will come out in my presentation, that it is the average young, normal observer we are talking about, the average young population who have 20/20 vision, and not the poorest observer, that the current levels of illumination are based upon.

IERI—ITS ORGANIZATION

Webster says a society is a voluntary association of individuals for common ends—an organized group living or working together, or periodically meeting or worshipping because of a community of beliefs or common profession. In 1906, Lewis B. Marks, a consulting engineer in New York City, felt the functional need of bringing together all individuals having an interest or designed concern in the application of light to seeing. This was still in the gas era of lighting and Mr. Marks himself was primarily concerned with the application of gas for lighting. Mr. Marks stated that the coverage of interest in the application of light would be broad. He stated, "The specialist in illumination, the electrical engineer, the gas engineer, the architect, the designer of electrical and gas fixtures, and of globes, shades, and reflectors, and the decorator—all will meet on common ground to discuss the question of illumination from every standpoint."

As with all societies, there is a pooling of information which underlies the progress in the development of new techniques and improved practices. Thus the practitioner, the educator, the eye specialist, the architect, the laboratories, and the company representative have all contributed papers with new information and discovery over a period of time. Some of the commercial companies found it to their distinct advantage to set up research laboratories by which to develop not only improved products, but also to discover improved ways of satisfying the visual environment.

Up to 1935, the results of research by these laboratories were used by the Illuminating Engineering Society (IES) as a basis for their recommendations to the consuming public. There was an inner desire on the part of all to produce the very best illuminated environment for seeing. We attracted many, like Ferree and Rand from Johns Hopkins University, and Dr. Lloyd Jones of Eastman Kodak—a whole series of scientists, including some of our founding members who, helped do research in this field.

From 1935 on, there were stirrings within and without the Society that there ought to be an objective research program initiated through the professional Society which would obtain results free from any possible inferences that the results would be commercially motivated. While it was believed that the research in commercial laboratories had been honest and sincere, it was now felt that the whole basis of the recommendations of illumination should be constructed from research done in university laboratories where there would be no commercial self-interest.

In August 1944 the Illuminating Engineering Research Institute was initiated as a separate, non-controlled research agency which should sponsor and stimulate research primarily in university channels. The Illuminating Engineering Society developed a Trust Agreement with a Board of Trustees who should conduct an "independent, non-profit, science-oriented organization to conduct fundamental studies of light and its relationship to seeing." These Trustees represent a broad spectrum of disciplines which shall bring all of their expertise to bear in operating a broad program of research into every phase of the application of light for the benefit and welfare of mankind. This includes not only seeing, but also the physiological effects of wavelengths as well, which is a new field we just recently started a few years ago with a seminar with fourteen medical researchers in the effects of wavelengths of light on the health and welfare of people.

The current Board of Trustees are as follows: Three university professors. Two ophthalmologists, Dr. Fonda (who is Secretary of the Joint Committee on Optics and Visio-Physiology of the American Medical Association) and Dr. Newell (who is head of the Pritsker School of Ophthalmology at the University of Chicago). One scientist from the National Research Council of Canada, Dr. John David Keys (an atomic physicist, who is Vice-President of the National Research Council of Canada and used to teach illumination in his earlier years). One architect, Mr. Herbert Swinburne (a prize-winning architect and head of the Building Research Advisory Boards Committee on Conservation). One businessman. Two IES representatives, the president and immediate past president.

Now, as to the overall personnel, since this question arose a little over a year ago, I put together a listing of categories of disciplines who were our people handling, processing, leading our program processing to its final conclusion. And so, if we can have the first slide? By the way, I would like to indicate that we have very much followed a parallel course to the American Society of Heating, Refrigerating and Air Conditioning Engineers. They started in 1919 in their research program to find out the effective thermal environment and the various aspects of controlling the thermal environment. We patterned our research program after theirs, with our technical advisory committees composed of university people and practicing specialists. However, we divorced it from the parent body in order to be absolutely sure there would be no commercial interest because, in every society, there is always a play of various interests. In order to make sure it was completely uninhibited and objective, it was set up as a separate organization.

Now, here we are, the personnel of IERI.

TABLE 1.—Personnel of IERI

2 MEDICAL DOCTORS
  OPHTHALMOLOGIST—PROFESSOR
  OPHTHALMOLOGIST—PRACTICING
2 ARCHITECTS
  PRIZE-WINNING PRACTITIONER
  PROFESSOR
6 PROFESSORS
  3 ENGINEERING
  2 PSYCHOLOGY
  1 OPTOMETRY
2 SCIENTISTS
  BUILDING RESEARCH CENTER
  NATIONAL BUREAU OF STANDARDS
1 SCIENTIST
  NATIONAL RESEARCH COUNCIL OF CANADA
7 INDUSTRY REPRESENTATIVES
  3 CHARGE OF RESEARCH
  4 PRACTICING ENGINEERS

Out of 20 personnel there, only seven are related to commercial practice. We think that is a good balance.

IERI RESEARCH

TABLE 2.—Elements of Environment

1. TASK (SURROUNDINGS IDEAL)
2. VEILING REFLECTIONS
3. BRIGHTNESS DIFFERENCES
4. DISCOMFORT GLARE
5. PLEASANTNESS OF INTERIORS
6. OLDER AND SUBNORMAL EYES
7. LIGHT AND HEAT
8. BIOLOGICAL EFFECTS

The research program is divided into several different elements.

The task, the amount of light on the task.—This is always the constant question over the years. How much light do we need for quick, accurate seeing? And so, first, the task—how much light is necessary for this if the surroundings are ideal. We found out from Lythgoe's work in England, in 1933, that you can depress the ability to see, the sensitivity to see, or you can enhance it, depending upon the brightness of the surroundings and the relative balance of those surroundings to the luminance of the background of the details of the task.

Veiling reflections in offices and schools.—While the IES has been advocating mat material for many years in their practices for schools and offices, we now find with sensitive measuring equipment that we merely drove the veiling reflections underground. They are now microscopic instead of obvious mirror type reflected images. We do not see any streaks or patches of brightness; but, if you will look through a microscope, you will see a whole brilliant array of little facets of brightness which are reflecting mirrors from the pencil graphite or inked characters and from the paper fibers themselves.

Brightness differences.—We have been working on this over a period of time. Dr. Boynton of the University of Rochester, and now his graduate student who is now a professor at the University of Virginia, have been conducting studies on the change of visual sensitivity due to brightness differences in the field of view—in order to keep this proper balance that Dr. Lythgoe found was so important.

Discomfort glare.—I really should take out the word "discomfort." We are concerned, both outdoors and indoors, with disability glare and discomfort glare. We are concerned in offices and schools and the confined environments very heavily with discomfort, because we have sort of refined out the disability glare because of control of the luminaires, but outdoors we have still very bad disability conditions. However, we are inclined to think that we should be thinking of both of them involved in interior as well as exterior.

Pleasantness of interiors.—Once having set up a proper seeing environment, what do we do about making this an interesting, livable, stimulating place. We believe that efficient seeing can be combined with interesting interiors that will make a lovely place to be. We have been trying to bridge the gap between the architect and engineer. The engineer is the gadgeteer who loves his gadgets and efficiency. We had one architect who has been very prominent, a former editor of *Architectural Forum*, who said, "Away with efficiency of seeing. Let's give them an interesting, stimulating place to be." Well, that is the sort of thing we want to overcome. We want to do both if we can and we are well on the way. We are instituting multidimensional psychological scaling as a new tool to try to bring out the vectors of subjective feeling in an environment and design the lighting accordingly.

Older and subnormal eyes.—All this other work has been done on young, normal adults, because it has been done in universities with students that come in from two to four hours at a time and make these measurements. We need to go to older and subnormal eyes and we are going to hear about this later on from Mrs. Blackwell on older eyes. We have not gotten around to subnormal yet. We need to get to these fairly soon.

Light and heat.—All our work described above involves light and heat, even though, now, our new light sources, white light sources (with the papers being presented at New Orleans next week), the metal halide sources are producing one hundred lumens per watt which is a considerable advance over fluorescent lighting or anything of this kind. Already, we are working on the design of new metal halide units that will fit in offices and schools and greatly save in the maintenance of miles of fluorescent lighting and will also save in wattage, in energy, greatly, because of the higher efficiency. By the way, we have in my office a new indirect torchiere using a one hundred seventy-five watt metal halide lamp and it is producing about six hundred watts of incandescent lighting, beautiful quality lighting in interiors. We got an old torchiere from a secondhand store, and a kitchen pot which we turned upside down over the base which formed the housing for the ballast and it works great. And then we have a new study lamp, certified "Better Light Better Sight" study lamp, which has a ballast in its base; and, with a hundred watts of corrected mercury we are producing the equivalent of two hundred watts in incandescent lighting. Now, these are some of the things we are working toward in a very practical way. But, nevertheless, there is always light and heat and we have to think in terms of what we are going to do with this heat. How can we best utilize the total energy from the fixture space to the living space? We have this on our program. We have not gotten into this phase yet because of the high priority of the psycho-physics of vision.

Biological effects.—I mentioned before the effects of the wavelength of light on health. We are now working on hyperbilirubinemia. We have set up an experimental laboratory with Dr. Jerald Lucey at the University of Vermont, who has been, I think, the leader in this country in overcoming the bilirubin buildup in premature babies, twenty percent of which have jaundice or hyperbilirubinemia. It started in England where a doctor threw light on a test tube of bilirubin and they saw a chemical reaction occur. This coincided with what the nurses were saying that, near the windows, the jaundiced babies were recovering much faster than those farther away from the window. And so he thought he would put the light on the body itself; and, sure enough, it worked. Dr. Lucey has followed two hundred cases for two years with no side effects where they have recovered in a few days from using localized lighting over the isolette. Now we are putting in a luminous ceiling where we can get various levels and find out if it is a low-level long time or high-level short time effect.

Most of the activities of life are guided by visual cues, either conscious or unconscious. If one stands facing a wall, preoccupied with conscious thoughts, and swings his arm out toward the wall, there is an unconscious visual feedback which tells him to decelerate and stop short of hitting the wall. I believe that most of us do not realize the enormous unconscious visual cues that guide one's activity from morning to night. One threads his way through the living room of a home that is littered with toys in every direction. One moves around or over the toys, avoids the chairs, and successfully negotiates the entire space while engaged in animated discussion. One drives through a mass of traffic while talking to associates and even gesticulates to emphasize his discussion. All of this involves a whole continuous train of visual images of the details involved. Of course, there are the conscious details that are involved in every industrial process, in every reading and writing task, in every form to be filled out, in every calculation that must be developed.

All of these details both conscious and unconscious are controlling the activities of life. They are visual cues that tell us whether we are on the right course or not. These visual cues are those with which IERI has to deal in providing the appropriate illumination for quick accurate seeing. With the increasing complexity of life, the missing of a few cues can set a whole train of circumstances in the wrong course. Therefore, IERI must determine the vast range of detail to be dealt with and the particular illumination necessary for each of the details. And may I quote to you recent evaluation measurements—the glass container industry, the miniature electronic circuit, the rubber tires and rubber products industry, the dairy farms, the poultry and egg processing, the atomic power generator plants, roadways, hospital surgery, airplane maintenance plants and steel mills—all done within relatively recent times to find out the amount of light necessary for those particular details and those particular industries.

In the 20's and early 30's, Weston, in England, made studies in various industries as to the effect of illumination. A series of official government reports were published as a result of these field studies. He became increasingly concerned that the relationships he obtained by increasing illumination from low levels in those days did not represent the true visual benefits obtained from improved illumination. Finally, he conceived that, in order to obtain these true relationships, he should conduct the study under simulated, controlled conditions in the laboratory where other complicating factors were not involved. He settled upon the use of Landolt rings, (the international visual test object), as the detail to be observed and he had them printed in paragraph form in different sizes, and eventually in different contrasts. He came to the conclusion that mechanical time involved in manipulation of most field tasks tended to conceal the visual responses, and, thereby, misrepresented the true relationship of visual reactions as a result of illumination. He therefore arranged for the subtraction of the mechanical time from the overall time in order to get the true visual response with illumination.

The Weston method of assessing tasks in commerce and industry was adopted by the British Illuminating Engineering Society in 1943. In 1945, the North American Illuminating Engineering Society adopted the Weston method as its basis for appraisal. However, as the Technical Advisory Committee on Light and Vision, headed by Dr. Glenn Fry of Ohio State University, began to study the Weston data, they concluded that Weston had not fully subtracted the mechanical time and also his papers did not reveal his statistical treatment of the data. They therefore decided that IERI should refine the Weston method and extend it to other factors that would be truly representative of work situations in the field.

In order to find suitable people to work in this field, the Chairman of the Board, Professor Strong, Cornell University, and the Secretary, C. L. Crouch, became participants in the Armed Forces National Research Council Vision Committee—it is the National Academy of Science Committee now and Dr. Benson is Executive Secretary—which represented millions of dollars being spent by the Defense Department in determining the visual responses of Armed Forces personnel in carrying out their military duties. It soon became obvious that Dr. H. Richard Blackwell of the University of Michigan was studying the very factors of visibility that would be of interest to IERI. The work was started in 1950 in a modest fashion, and culminated in a method of assessment in 1958. It was realized at that time that there were many other factors that needed to be investigated before a complete comprehensive method could be established. However, architects and engineers have to keep designing and building and so, at any particular time the latest information must be utilized for the best results to date.

Shortly after the move of Dr. Blackwell from the University of Michigan to Ohio State in the early 60's, Dr. Stanley Smith took over as the main researcher in the field of quantity of illumination. He continues to investigate factors that are involved in everyday work situations that will have a bearing on the eventual formulation of a complete specification of the appropriate illumination to be used. Further, Mrs. O. M. Blackwell has continued to make studies for IERI on the effect of age. (Dr. Smith is limiting his studies to the young normal adult as the basic formulation and then we will add factors of age.)

I would like to show you two slides of Dr. Smith's work. He is doing a needle task. Now, this does not represent just needles. It represents a complex task of manipulating detail in industry in particular. And so he has a nylon fiber that must be inserted in ten needles, each of which is a different size. Everyone goes from the smallest needles up to the larger needles. He does it under different levels of illumination and finds out what the production is as you change the levels of illumination—what is the production and what are the errors related to the accomplishment of this task.

Then he has the coin task, and this is the Lincoln penny test. He has the person to read the last two digits of every Lincoln penny. And there is a whole series of Lincoln pennies with decreasing reflectance and increasing crud on them, so that you have all the way from good contrast to poor contrast. This does represent, metal working industrial tasks, since I was an industrial specialist. You largely see all metal working tasks by reflection of a large image in the somewhat specular background of the details to be seen. So this represents very well the detail that you have in metal scribing, die layout work, the printing industry, the composing stones, all of this is represented in that kind of task.

Now we come to age. Here we start with the idea of advancing from infancy, elementary school, the twenties, the thirties, the fifties and the sixties; and these photos were of actual persons. One man in the sixties said, "Cash, I don't look that bad; I know I don't look that bad." But you will notice the facial characteristics that change with a period of time and Mr. Weston presented a wonderful paper in 1954 on the facial effects as evidence of the effects of age on seeing.

Here is a slide of Mrs. Blackwell at her task, at her control board, which sets up an automatic train of pulses; and here we have the older people making their measurements. This is for static viewing and right now they are engaged in dynamic viewing. This work has been published already on one hundred fifty-six observers in enough population in each one of the ten-year intervals to be able to find out what happened with every ten-year interval of age and how it shifts the visual performance curve. This is for one-fifth of a second exposure.

Now, how about the visual characteristics of age? Life expectancy has gone from forty-eight years in 1900 to seventy-five years in 1970, almost a linear line.

Here is the pupillary opening. It decreases until there is no flexibility left at seventy-five years of age; and so you can not graduate the amount of light coming in through the pupillary opening.

Here is the relative visual acuity curves over the years and decrease of that visual acuity (Figure 1).

Here is the speed of perception, and this is Weston's work on speed of perception according to age, in England; and you will see there is a dramatic change.

Here is critical flicker fusion and the change of sensitivity with age at various angles with the line of sight.

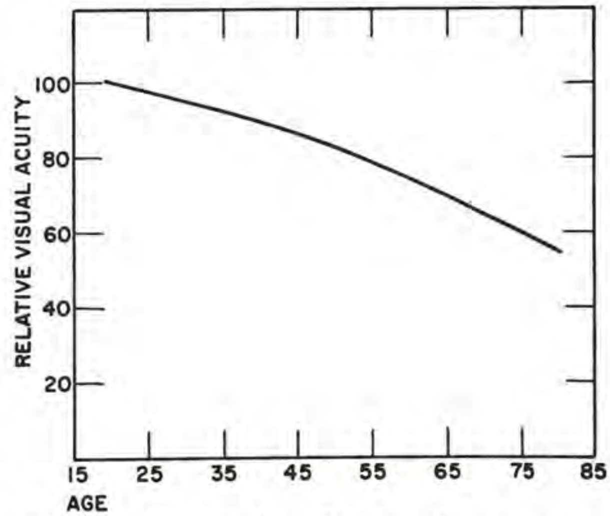

FIGURE 1.—Relative visual acuity vs. age.

Here is the brightness threshold, where there is no size factor involved, just the determination of the reduction of brightness sensitivity with age to one half value.

Here is the transient adaptation, where the fifteen-year-old can completely adapt in going from indoors, a brightly lighted interior, to outdoors in six minutes. But look at the seventy-five-year-old up to the eighty-five-year-old and it takes him thirty minutes. So, when he starts out driving from a brightly lighted interior, he is partially seeing, partially blind in trying to guide his vehicle.

Here is resistance to glare, which is disability glare, and this was done with several hundred thousand observers. This was disability glare with motor car headlighting involved, and you will see that he can hardly get started at the age of seventy-five. It is glaring to start with. By the way, this was a simulated two-lane roadway, object in the lane down the road, headlights coming toward you; you moved a lever, the headlights came toward you until you could see the object. The amount of movement there represented your resistance to glare.

In 1958, the illumination levels were changed because of the new, more comprehensive basis as compared with the previous meager data. The new visual performance method asserted that contrast is the dominant factor in visibility of the range of sizes of details that are critical for seeing in commerce and

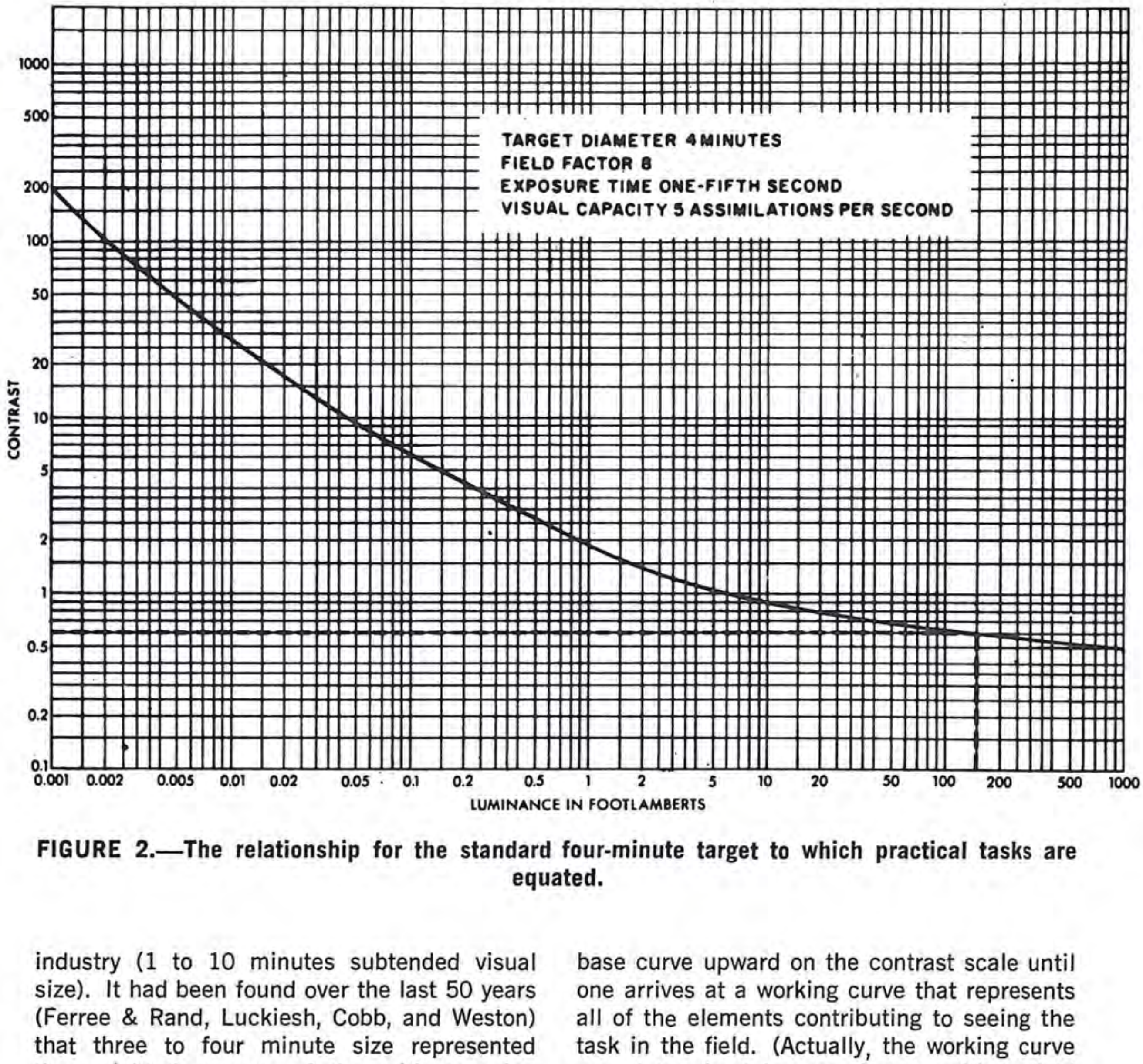

FIGURE 2.—The relationship for the standard four-minute target to which practical tasks are equated.

industry (1 to 10 minutes subtended visual size). It had been found over the last 50 years (Ferree & Rand, Luckiesh, Cobb, and Weston) that three to four minute size represented the weighted average of the critical seeing tasks in working situations. Therefore, the basic curve of contrast versus luminance for a four-minute circular disc laboratory test object formed the foundation of the method for determining the light necessary for seeing in commerce and industry. This basic curve shown in Figure 2 was established in the laboratory at a threshold of 50 percent correct seeing. We could go into the philosophy of why it was done at that point on the probability curve.

Of course, there must be field factors between 50 percent probability of seeing in the laboratory and the actual conditions in the field. It has been found that these field factors, determined in the laboratory, displace the base curve upward on the contrast scale until one arrives at a working curve that represents all of the elements contributing to seeing the task in the field. (Actually, the working curve was determined by experiments with a field task simulator. The elements contributing to the final working curve were estimated from other experiments relating to these particular factors.) Thus there is a family of parallel curves, each one representing the additional component of that element found in the field.

This is the field task simulator. This represents what we find in commerce and industry time and again. Here are fifty four-inch plastic discs with optics below them in a cylinder. The black items are switches. And so the person stood in this booth and the levels of illumination were changed and the wheel speeds were changed and the discs came through—there were six of these in the cubical

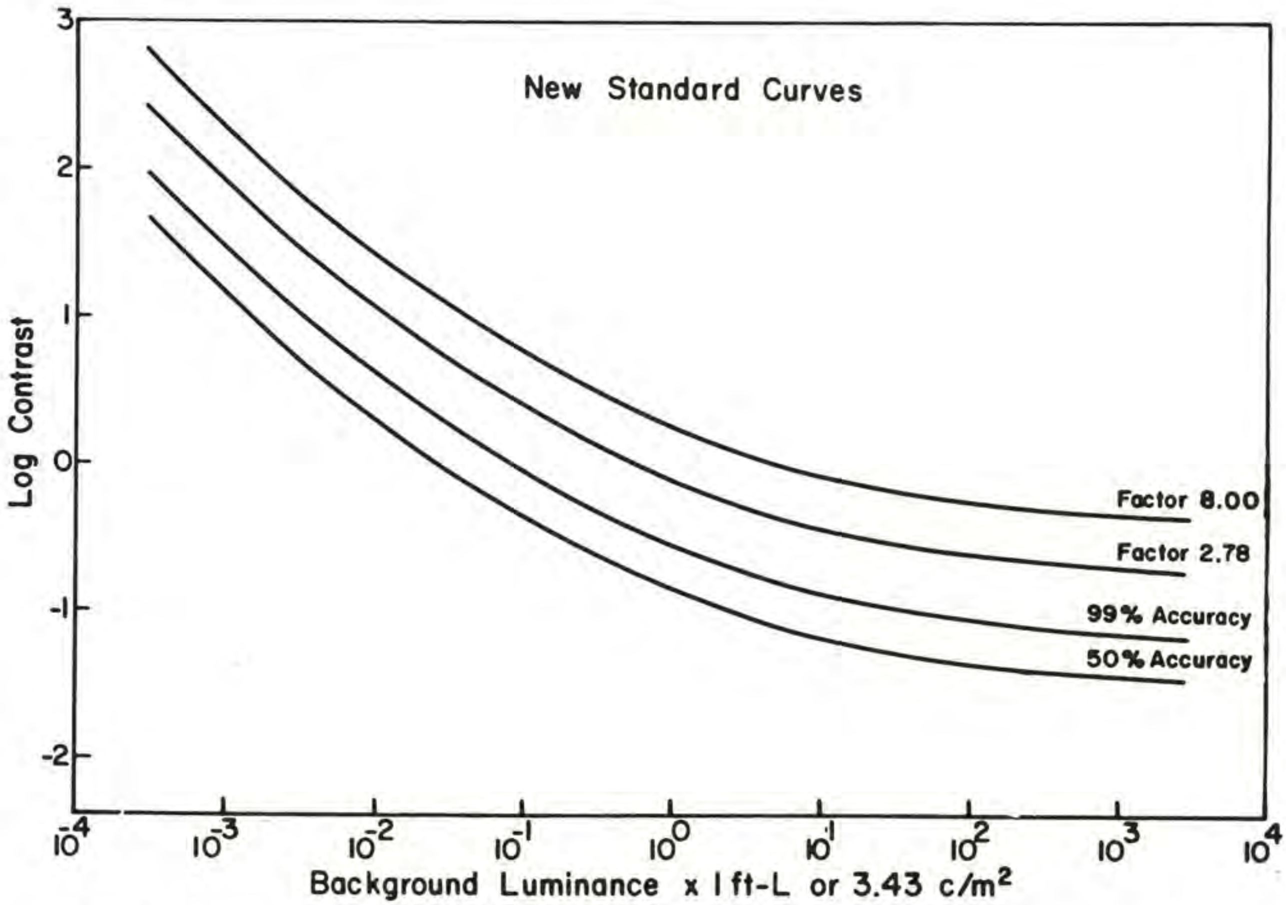

FIGURE 3.—The relationship between threshold contrast and background luminance for the field factors of 2.78 and 8.00 and for 50 percent and 99 percent accuracies.

at any moment of time. The person discovered there was something wrong out of the corner of their eye, fixated briefly, and slammed the switch which recorded automatically. Then they kept on cycling in their study. Now, this is commonly found in industry, on conveyor belts and inspection jobs of this kind. This established the working curve. And it is found in offices, because of the constant scanning movements that one goes through in offices and schools.

Here are the parallel curves showing, in Figure 3, fifty percent accuracy, ninety-nine percent accuracy; the unknown location, 2.78; and, finally, the moving-eye conditions, dynamic conditions, resulting in a working curve of eight above the threshold, displacement on the log contrast scale of eight. We used the upper curve as our working curve and we relate all tasks in the field to that upper curve. We find a particular contrast of a particular object out in commerce and industry and we bring it in as an equivalent contrast and locate it on the ordinate. Then we go over to the curve and down to the background luminance and find out how much luminance is supposed to be used, divide by the reflection factor and we get the footcandles involved.

Here is the visual task evaluator in our office being used on an office task. We run calibration curves on all of these observers to know what their relationship is to the population of the thirty to forty-year-olds. And so we maintain our relative calibration all the way through.

Here is the optics of the visual task evaluator which is merely a contrast threshold meter which maintains the adaptation constant so that you do not change the sensitivity of your eyes. You change the contrast wedge and find out what the contrast threshold of that particular object is in the field.

Here is a typical task found in the field, reproduced material which the observer was looking at through the visual task evaluator.

Visual Task Evaluator (VTE).—Here it is taken out in the roadway, West 76th Street, on crime study, cooperated by the New York City Lighting Department—they were very enthusiastic about this. You want to know who the people are that are coming toward you two hundred feet away, one hundred feet away and fifty feet away. And so we made measurements of a Caucasian, a Negro and a Spaniard, so that we would have all of those characteristics.

Here is the visual task evaluator being operated at the left and the City man is in the back, and the disability glare meter which can measure the loss of your sensitivity right here.

Then we have used it in hospitals, Montifeore Hospital; and we were measuring the tissues, the sutures and other details. This happened to be preparation for open heart surgery. We got this shot to show the setup of our arrangement. We were in another room, and we projected through a small window to a mirror and looked right down into the operation itself. We were able to make measurements. This slide is just a rough idea of the type of tissue—some tissue is bad, it is fatty, and some is lean that you can tie to and it will not break loose; and the sutures vary all the way from tiny, tiny sutures for openheart surgery to heavier sutures.

These elements of the formula for required illumination include: degree of accuracy of seeing the detail out of the number of times it is present, the unknown location of detail versus the known location, and the dynamic viewing (eye movements involved in performing an actual task) versus static viewing. The top curve of Figure 3 representing the incorporation of all these elements becomes the field use reference curve.

For the last fourteen years this has been the framework of arriving at the working curve for specifying the illumination levels. The working reference curve has not changed much even though the values of the elements contributing to it have changed. It was expected from the start that the values of the elements might change as a result of further research and even the location of the working reference curve might change depending on the magnitude of the elements contributing to it. For instance, the element of dynamic viewing might change radically, depending on the complexity of eye movements involved in particular visual work in commerce, industry or sports.

This item, together with uncertain or unknown location, probably accounts for the greatest impact on the location of the working reference curve (and therefore, the illumination required). To aid in the resolution of the two elements, it has been necessary to develop an eye-movement recorder and to carry out practical tasks of sufficiently different characteristics to record a range of eye-movement patterns. With a series of particular eye-movement patterns, the laboratory can establish field factors for different categories of patterns. It may be that there will evolve several working reference curves for diagnostic field use. This work is now underway.

There has existed from the beginning of the system a need to answer the question as to whether it pays off in real gain of performance of field tasks over previous empirical systems of determining illumination values. A few case histories of production gains and reduction of errors were available to show the difference between former levels—before 1958 and those after—and the system determined levels. Since the question keeps recurring, and it is recognized that field location tests are subject to many complexities of physical and psychological factors, it was decided to conduct a series of representative tasks under carefully controlled conditions and varying illumination levels. From these production tests, one could determine if there were meritorious gains from the system-determined levels. These tests validate the system and this work is now underway.

As a homey illustration of the rationale for the current footcandle levels, I am calling your attention to three eye charts based upon the original American Medical Association eye charts (which is the reverse of the Snellen). The black on white represents reading of textbooks and printed material in schools and offices; the gray on white represents sewing on light cloth in the home and shop or pencil-work carbon copies and duplicated material in the school or office; the black on dark gray represents sewing on dark materials, cooking dark foods in the kitchen or working on dark materials in industrial processes.

Now, what light did it take to see the charts? We took twenty young, normal adults and put them at a twenty-foot distance from the full sized charts. They rheostated the illumination up and down until they could just barely see it. They found that one footcandle illumination was the average—half of them could not see it and half could—for the 20/20 line, one footcandle illumination. The gray letters on white (21% contrast) required one hundred twenty footcandles under the same set of conditions; and the black on dark gray chart required five hundred and twenty footcandles. All they did, really, was proportion the illumination in accordance with these various factors. We have, now, a formula for doing it, but we knew the principle all along. Further, when people come to the bifocal age, they walk over to the window immediately where there are hundreds of footcandles.

We recommend that you try it for yourself. I have little eye charts now that are miniaturized; you can hold them up at two-foot instead of twenty feet. I want you to use it on yourself and see whether you have normal vision or not. If not, see your doctor. Then I want you to turn off the lights and go over here in the darkest corner and see how far up you can see on the chart. And, then, holding it there like that, walk over to the window where you have hundreds of footcandles and see it come out—the whole thing comes out. Even the dark chart comes out. It takes more, much more light; but, under normal daylight, with hundreds of footcandles of illumination outdoors, this will come out as well. So, really, we have a rationale, a homey rationale, for the use of illumination.

So many people talk about reading. This is the very best contrast, ninety to ninety-five percent contrast, and you do not need high levels. IERI data shows this and IES recommends only low levels. Some people jump at the conclusion, because of reading tasks like this, that IES and IERI recommend several hundred footcandles. On the other hand, we have found on perching boards for suiting material that we need two thousand footcandles. We find they can not see defective threads with less than two thousand footcandles provided by localized lighting. IERI is not interested in how you do it; we are only interested in the light on the task to be seen and the brightness balance of the environment. So the story has been distorted. People use the higher levels and say the IES and the IERI recommend this sort of thing.

Of course, you have noted in all of this discussion as to the background of the current levels of illumination, that the research has all been related to visual performance and the general subject has been called the psychophysics of vision. Naturally, in our type of civilization and culture, the emphasis has been on the ability to see quickly and accurately because our concepts have to do with production in commerce and industry. In general, our thinking has not encompassed the physiological aspects of vision or the possible visual dysfunction and stress that may occur with the lower levels of illumination.

In earlier years in the IES and medical literature, there had been an expression of the relationship of lower levels of illumination to eyestrain. Dr. Lancaster, a famous ophthalmologist, described eyestrain and described its relationship in a medical text as to the illumination level. Ferree and Rand, and Luckiesh and associates pointed out in the 20's and 30's that there were fatigue effects related to lower levels of illumination and there appeared to be a relationship between this fatigue and the physical symptoms that eye specialists described as eyestrain. Little follow-up has been done in recent years because of the preoccupation with quick, accurate performance. It would now appear that we should have been pursuing some of these earlier studies in order to answer the questions posed by NIOSH today.

However, we do have a possible approach to this situation through the recent work of Dr. F. W. Hebbard. He found that there is apparently a much greater requirement of ocular motor adjustment with low levels as compared with high levels. He found this was true also with glare versus freedom from glare. At this point, we are inclined to think that there may be a real change of pattern of eye performance with lower levels as compared with higher. This could be construed as evidence of visual dysfunction from the normal pattern of eye performance under nature's levels of illumination. You will hear much more about this from Dr. and Mrs. H. R. Blackwell.

And, now, I just want to end with a few slides. What are the kinds of tasks we are dealing with because we are talking largely about offices, and, to a slight degree, about schools? This is Dr. Hebbard and his setup at Ohio State University. He put on the eye of the observer a contact lens with an arm with a mirror on it and he shot a beam of light toward the mirror and by the lever arm it was amplified and recorded on the recorder back at the back of the room. This is his setup and bite bar to hold the head rigid. He found out there was a great deal more ocular adjustment action with low levels than with higher levels and with glare than without glare. I want you to hear about that from Dr. Blackwell.

Now, what are the tasks found in government buildings? A survey was made and here is a typical type of printed material. Here is a form that was taken right from the offices where they were performed. The survey was made in the Department of the Navy, the Internal Revenue Service, and the Veterans Administration. Here is a young lady who does this work all the time, transcribing from pencil handwriting to typewriter form. This is the thing that she was working on. This is the sort of thing where you have poor contrast in this operation.

Here is a young lady working on forms. Here are the forms that she is working on and the contrast is not good. Here is another form. If you take those figures, the contrast is pretty good; but other details are not so good.

Here is a general office and how it was lighted and the typical interior. Here is a man at the Veterans Administration analyzing medical reports all day long. Here are the forms that he was working on. And here is a closeup of the detail he had to work with.

Here is a lady working on some more forms; and, again, the contrast was poor. Certain things are good. You can see the black ones show right up boldly, but the others are grey. Here is a closeup of some of this work. Here is another form normally made out in pencil. Here is another one.

Here is a lady who may experience age effect. In IERI and IES we are talking only about young, normal adults in all recommendations. I just wanted to give you a taste of what actually occurs in the field and the relatively poor contrasts involved.

Thank you, Mr. Chairman.

DISCUSSION

Chairman Heins: One point that has been brought to my attention is that we are using the term "low levels of illumination" rather loosely. By "low levels" we are referring to levels which are below the values recommended by the American National Standards Institute (ANSI A132.1–1973—Office Lighting, ANSI A11.1–1973—Industrial Lighting). Perhaps we should be a little more specific in our use of the term.

Dr. Blackwell: Why do we not just leave it that the problem here is at what point in reduction of illumination do you get into health problems? That is what you really want to know.

Dr. Halldane: My general comment is, because of the energy crisis, our problem here is lowering lighting levels. And so, it is a political problem of lowering at the moment, because we are going into a lowering process. It is not as though that we are going to a lower level or what it is, but here GSA and NIOSH are involved in a political process of lowering the levels because of energy conservation. I think that "lowering" is the better description which reflects the political and the technical problem that they have at hand.

Dr. Weale: Would we get around this by using the term "reduced" rather than "lowered"? The term "low level" has certain connotations which are obviously causing the difficulty which the Chairman has just mentioned.

(And so, the word "low" was replaced by the word "reduced" in the title of the symposium.)

LIGHTING AND HEALTH HAZARDS

David G. Cogan, M.D.

Dr. Cogan: I am the "no expert" on the panel, merely an ophthalmologist who has had some tangential contact with illumination but insufficient to give me much authority in the subject. Moreover, I should say that although I represent here the National Eye Institute, nothing I have to say necessarily reflects the opinion of that Institute. In fact, I have not heard the subject of illumination discussed in Bethesda, Md.

My presentation can be summarized in a single sentence. No organic disease of the eyes results from low illumination. Of the various ophthalmic diseases which we are called upon to treat (glaucoma, cataracts, retinal degeneration, etc.) none are influenced by use of the eyes in so-called poor illumination. Miners' nystagmus, which is often cited as an exception, is a controversial subject in which many factors other than lighting are involved, and has no recognized counterpart in other occupations.

Of course, my comments have to do with the possibility of disease and do not bear on the esthetics of lighting, the quality of lighting, or the efficiency of work functions with lighting. I would judge, from this morning's discussion, that you would agree with me that low levels of illumination do not cause any disease state in the eyes but the public has the opposite opinion. The public has the opinion that low levels of illumination is doing harm to their eyes and to their babies' eyes. This impression has been fostered by the commercial interests in the lighting industry.

Some 35 years ago I took issue with the rampant commercialism and, being charged with writing an annual review article on ophthalmology, I emphasized the obligation of the medical profession to reassure the public that no serious health hazards were involved in "poor illumination." It is probably fair to say that this represents almost unanimous ophthalmological consensus but few ophthalmologists have been sufficiently concerned to carry the message to the public or even to the general medical profession.

This then is my comment on Point 1 of the question posed by Chairman Heins in his initial charge to us. There is no substantial evidence indicating eye damage, permanent impairment of visual functions, or eye disease from working under low levels of illumination.

Another, and related, question which has been raised, bears on the nature of "eyestrain." In the minds of most persons this suggests something akin to a muscle strain in one's limbs and is a definite concept. But ophthalmologists have difficulty in defining eyestrain in any such definite terms. Rather it is an effort syndrome and therefore more psychological than physical in which a visual task is performed under difficult circumstances. Headache, irritability, nausea and other symptoms may be brought on by continued visual tasks which are rendered difficult by refractive errors, ocular motor aberrations, insufficient illumination, or glareful conditions just as they may be brought on by persistent listening to music with the hardships of low levels of audition or in competition with distracting noises. Yet in the latter case it would be ridiculous to talk about ear strain with the idea that we were doing organic harm to the ears. The basis for eyestrain is similarly tenuous. It would be better if the word eyestrain were deleted from our vocabulary.

Dr. Blackwell opted for deletion of some word in this morning's presentation. What was that word?

Dr. Blackwell: "Unnecessary."

Dr. Cogan: I would opt for deletion of "eyestrain" since it has such ambiguous implications. Perhaps we should use the professional term, asthenopia, which does not suggest an analogy with strain of a skeletal muscle.

DISCUSSION

Mr. Caplan: I am concerned about your comparing this to hearing and noise where you definitely have two kinds of a strain: a permanent strain, such as a permanent threshold shift, and a temporary strain which is a reversible type of reaction. Are you suggesting that there is no such thing as a temporary threshold of seeing?

Dr. Cogan: Right.

Mr. Caplan: Are you suggesting that there is no temporary thing that goes back to full use?

Dr. Cogan: No more than there is for hearing, no.

Mr. Caplan: There is for hearing.

Dr. Cogan: Low levels of hearing?

Mr. Caplan: No, for high levels, (of noise).

Dr. Cogan: I would like to talk about high levels later. High levels of lighting certainly can cause damage to the eyes. I would like to come back to this in a minute.

Mr. Caplan: Okay, but I am wondering whether you have a loss of ability to see from the low level, temporary as it may be.

Dr. Cogan: Right, I think you do. At low levels you have trouble seeing. If you try to do anything which is a difficult task, you are going to end up with a headache and other symptoms. But that is not damaging your eyes.

Mr. Caplan: The fact that it is temporary does not necessarily mean that it is not disease, because disease may be permanent or temporary. You may have a headache, or other symptom, in other industrial exposures. For example, it is not acceptable to create a situation such as carbon monoxide exposures, that causes headache, which is completely reversible.

Dr. Cogan: The point I am trying to get across is that there is no physical damage to the eye as a result of this, any more than working too hard in the garden.

Dr. Halldane: That is physiological, no behavioral, or anything like this. You are only speaking of the physiological.

Dr. Mead: Well, primarily, sir, you are talking about input to the eyes, the seeing, the optical part. The fact that the eye, if it works under difficult conditions, you do get muscular strain from the muscles in the head, neck, back, and so on. At the end of a hard day's work, you develop strain, muscle strain in both striated and smooth muscles.

Dr. Cogan: I had not thought of headache in this connection. What muscle goes into spasm?

Dr. Mead: Neck muscles, back muscles, if you work hard enough while seeing.

Dr. Cogan: Is that so?

Dr. Mead: Yes.

Dr. Cogan: I personally get symptoms, but I do not get back strain. Maybe in this case it ought to be called "back strain" rather than "eyestrain."

Dr. Halldane: I think what we are coming at is the distinction between "stress" and "strain" in the behavioral sense. Generally, we speak about "stress" as the environmental distress or the exterior physical thing that produces the strain in the system itself. Now, generally, we can measure the stress or the stressor, but we have no availability of measuring the strain in what you are speaking of. I think this is the difficulty that you are getting at i.e., what is measurable. And so your objection to the word "strain" is legitimate, because we cannot measure it, and, therefore, it is not very constructive. Now, if we talk about the stresses of an environment and why it impedes behavior or people's physiological responses, you use the word "impeding." And then, if it is nonreversible, you talk about "impairing." Now, I think we get out of that trouble. All right? So we can talk about impeding physiological responses to the extent of impairment where it does not return to its original condition. This might get over that semantic hangup that these sort of discussions always tend to get into.

Dr. Cogan: Yes, I do not know whether it is worth pursuing too much, because it is a matter of semantics. What I am objecting to is the public's interpretation that you are doing something organically harmful to the eye from low illumination. That is what I am saying "no" to. That is what the public identifies with the word "eyestrain."

Mr. Nelson: Yes, there is also the fact that the question on impairment as it is brought back here, industrial impairment, daily headaches, et cetera, that are unacceptable on a job. Such things built in a job might be unacceptable in a clerical job, also. But the feedback I get are terms that I would call "discomfort," "annoyance," "personal dislike" and so on. What I am concerned with is passive impairment or reversible impairment which is probably a broader spectrum range than, actually, permanent impairment; and it is being used and expressed as one point, or one place. And, if we move into that, again, I am very anxious that we quantify it somehow.

Dr. Blackwell: May I make a small point? I agree with you thoroughly. I have not been aggressive enough to do it for the last few minutes. I agree with you thoroughly about your main point, which is that there is no anatomical change with low levels of light. I wanted to make the point that, in your analogy of the other sensory systems, if one is impoverished for information, there may be a claim of stress which may produce impairment; but there is a very obvious and important difference between the ears, the nose and the eyes. And that is that the eyes have the well-known ocular motor systems which are servo-driven by information and that the ears do not. Our ears do not rotate. Our nose does not change its properties in order to smell; it is a passive detector. Now, the eyes are not. I hope to simply remind you, if some of you are gone by the time I have a chance to talk this afternoon, that I am going to be talking about the ocular motor systems, which, in my opinion, are clearly implicated as the reason for symptoms. When peoples' ocular motor systems do not operate up to their ultimate precision because of low levels of visibility, which can be produced by low levels of light under some circumstances, this corresponds to symptoms. And I would have to object—and you agree with me, of course—that the eyes are not like the nose or the ears in this rather important respect. I am speaking of accommodation. I am speaking of binocular fusion, of conjunctive eye movements. It is the eye muscles that are involved here and I want to bring this out later this afternoon.

Dr. Cogan: Could I say something else, though, in another tack? The reverse, it seems to me, is very relevant to our deliberations. It is not on the program, but it has been suggested several times that excess light is potentially damaging to the eye. We have long known, of course, from cases of eclipse blindness, that if you get enough light in the eyes, you produce retinal degeneration. We have also observed, occasionally, sun gazers who damage their eyes by looking at the sun. I have recently examined a prisoner of the famed Charles Street Jail in Boston who looked at the sun with one eye for two hours and the other eye for four hours and ended up with typical macular degeneration in both eyes.

But viewing of the eclipse or the sun—and the same holds true for exposure to the flash of an atomic bomb explosion or to a laser beam—involved such unnatural and intense exposures that we did not consider them in the sense of occupational hazards. Then, a few years ago, Werner Noell in Buffalo reported the blinding of mice by continuous exposure to fluorescent lights. This was abundantly confirmed by Dr. Toichiro Kuwabara. Dr. Weale referred to similar deleterious effects on other animals and Dr. Ephram Friedman and his collaborators have shown comparable effects in human beings after prolonged exposure to the bright lights of indirect ophthalmoscopy.

We do not know whether or not such exposure to light can cause macular or other retinal degeneration in man but that possibility is being explored by Dr. Mark Tso and his collaborators at the present time.

In this connection it may be of some interest to point out that the retina is transparent and does not therefore absorb light that is focused on it. But, immediately behind the retina is the pigment epithelium which is highly absorptive of visible and infrared radiation. The heat generated must be efficiently dissipated and for this we have a very vascular membrane, the choroid, which presumably acts as a radiator.

But, with the slowing of circulation with age, this heat radiator may become less efficient and it is not inconceivable that the retinal degeneration which occur predominantly with age, such as macular degeneration, may result from exposures to light that are harmless in younger persons.

Thus in reply to our chairman's request for suggested lines of future research I would propose the study of the harmful effects of excessive light instead of pursuing the chimera of harm from insufficient illumination.

Mr. Crouch: I have had occasion to examine Noell's work and Kuwabara's work. I have analyzed it and found that they apparently made some mismeasurements, physical measurements of the intensity of the light; and they could not possibly have gotten the levels that they got. I explained this in rebuttal to your article in the *Sight Saving Review*. And then we had Dr. Noell at a seminar two years ago last March and he told us that human beings have a mechanism which protects them, which the rats and mice do not. So that this could not be extrapolated from rats and mice to human beings. Of course, we know that the rats and mice have primarily rods and human beings have cones. They are a nocturnal animal. And the tests that were run were continuous exposure with no relief to the rats. They were surrounded by a bank of fluorescent lamps clear down to the horizon; they could not get away from it. And they were kept in continuous exposure until they burned out their retinas. So, actually, there was a nonuniform damage. It appears that what was happening was the projection of images of the tubes upon the retinal surfaces, because the eye acts as an imaging media. And so these rats, who could not get away from this thing, were registering images. The rats and mice tend to freeze under an unnatural environment. So they were projecting these images in a way that a certain part of the retina was more damaged than others.

Now, Dr. Tso has repeated the same kind of an error, and I notice it is picked up by others recently. Bruce Boyer of the Environmental Protection Agency, with whom I have been in correspondence, was using this in the Washington *Star News* as an answer to the editorials of employees of the General Services Administration. He sent me all of the data, and there is a *J.A.M.A.*, March 12th, 1973, Medical News, which infers that, according to the title, "Long, Well-Lit Lives May Lead to Eye Damage."

> "Is macular degeneration the price we pay for living longer in better light? .
> No one can say for sure, but Mark O. M. Tso, M.D., suggests physicians should at least consider the possibility that some forms of macular degeneration may be related to the cumulative effects of a well-lighted lifetime, including its hours devoted to television watching.
> Dr. Tso, a Research Associate of the Armed Forces Institute of Pathology and Assistant Research Professor of Ophthalmology, George Washington University Medical Center, told a Research To Prevent Blindness (RPB) Science Writers' Seminar in Los Angeles about work with twenty-four monkeys."

Now, Dr. Boyer was kind enough to send me the original paper, published in *The American Journal of Ophthalmology*, May, 1972; and what Dr. Tso did, was to use an American Optical Company indirect ophthalmoscope with a 20+ lens and put it continuously on the rhesus monkeys for one hour. As a result, he then showed pictures of macular degeneration. I felt he was committing the same error as Kuwabara and some of the others, because what was happening was a projection of the image of the source was being put directly on the retina. So I wrote him a letter as a result of Dr. Fry's suggestion and asked him if he would tell me the brightness of the image that was projected on the retina that caused this, and whether he measured, by a photoelectric cell, the beam only. Because the error that occurs in this, they take a big enough cell, and then they average it. They average a high intensity over enough area and they get a low level response from the photoelectric equipment. And so I wanted to know what the density was in the image itself and then also the beam, because it was twenty to twenty-five centimeters from the cornea of the eye that it was directed.

And it says here that the focused "maculas of nineteen young adult monkeys were exposed to the light of an indirect ophthalmoscope with a 20+ lens continuously . . ." Then it says they focused this: "The filament of the electric bulb was focused on the fovea. The central column of bright light from the ophthalmoscope was completely within the pupillary zone. The position of the ophthalmoscope was verified by direct observation every five minutes or less to make sure that there was no alteration in the area of exposure."

Now, I have taken it upon myself to write to Dr. Tso and he said, "I don't know. We don't have instruments here to measure it." He also said, "I think this is a very important issue. Would you please find out what it is. I therefore urge you to actively pursue in this direction to remeasure the illumination of the filaments as well as the whole profile of the beam."

So I got in touch with the American Optical Company and they responded very nicely, and said, "I believe that he probably used the old AO Model 11260 indirect ophthalmoscope with a less efficient heat filter. We made some measurements, and that instrument with a +14 diameter lens was 7.55 volts with a tungsten bulb. Our results were: total radiance, 4.4 watts per steradian per square centimeter; and the visible radiance was 0.88 watts per steradian per square centimeter." Of course, this shows a great infrared component with very little visible. But, on the other hand, I have found out that if you project the visible image on the film and put it sharp on the retina, that this is 700,000 footlamberts projected on the macula. This is fifteen times white snow under five thousand footcandles. We are recommending seventy footlamberts and this is seven hundred thousand.

Dr. Blackwell: Even without the infrared.

Mr. Crouch: That is right, even without the infrared. So what is happening is these medical researchers are not measuring what they are getting. So, therefore, we cannot use the material as related to what is happening to ordinary light.

Dr. Weale: I think I can throw a little light on this, if I may coin a phrase. I have done some experiments on my own eye which relate pretty accurately to what Dr. Cogan has told us about Noell's experiments. I think we have to remember, in connection with what Mr. Crouch has just mentioned, that Noell went out of his way to show that it is only light which is absorbed in the rods which produces the sort of degeneration he reported. Therefore, infrared can be effectively ignored in this particular conference. It is only light which is absorbed which has the actual spectrum of rhodopsin that matters. I am quoting from memory—I was not prepared for this—but I seem to remember that Noell also says that, in his experiments, about seventy-five percent of the rhodopsin was bleached. This gives us a measure of the intensity in physiological terms. When I bleached the rhodopsin and cone pigments in my own eye, I bleached them to completion and I compared the intensity of a summer sky in order to arrive at a biologically meaningful value with the sort of intensity that is needed to produce complete bleaching. We shall not be worried about focusing or filaments or anything like this. I will tell you that, when my pupil is fully dilated, and I view a London July sky—which was pretty bright at the time—for thirty seconds, I bleached about eight percent of everything that I can bleach using, for example, a Xenon arc with a heat absorbing filter. As Dr. Blackwell just said, the pupil was fully dilated, but, of course, I used it only for thirty seconds. If the pupil is not dilated, you can cut it down by a factor of ten, if you like.

Dr. Blackwell: Why not sixteen?

Dr. Weale: Well, we are discussing orders of magnitude. But the point that I want to make very strongly in support of what Dr. Cogan has told us, even if there is no linear relation, no linear reciprocity, there is a prima facie chance, we will put it no higher, a prima facie chance that senile macular degeneration—and I have never heard it said before today—could be linked to this sort of thing. You ask yourself, why are rods not affected? I think the answer may, on the face of it, be pretty obvious. We have shown that you need the same number of light quanta to bleach foveal cone pigments, and rod pigments. They are equally sensitive. To that extent, therefore, any physiological effect which may be attributed to one ought to be attributed to the other. But the rods are protected by the absorption of the crystalline lens to an extent which is not available to the cones. To a certain extent, there is macular pigment which will take care of the sort of radiation which would affect the rods. I think, therefore, that from this particular point of view—it is stretching things a little—the cones are particularly vulnerable and I would like to support Dr. Cogan very strongly in his suggestion that here is a field which certainly merits attention. One does not want to spread any alarm, but this is a thing which ought to be disproved pretty soon.

Dr. Blackwell: Would you not agree, both of you, from the accumulated knowledge from many laboratories that we can be certain that illuminance from an extended source, be it a sky or a light fixture, of two thousand footlamberts creates no normal problem. Taking your numbers, for example, the sky on a bright day and allowing for the change in pupil size, I would get a safety factor, surely, which says that two thousand footlamberts is no problem. Actually, the most sensitive experiments, not the ones you are reporting, were those of Sperling. Sperling was picking up changes that are so small you can see nothing at all histologically. But, in monkeys, he showed that there were long-term changes in the function of, let us say, one cone type, which made it perfectly clear that there was enough absorption to do something. Pressed for numbers, he comes out with numbers that make sense in terms of our experience with the out-of-doors world, which is that, truly, you have to be talking about ten, more likely twenty thousand footlamberts before there is trouble. Now, my point is the following: Luminaires might reach two thousand footlamberts as an absolute maximum; surfaces in a room never do. You are talking about fifty footlamberts, not five hundred or five thousand. So, with all due respect to caution, what we would have to say, I think, is that there is positively no reason for concern about anything except luminaires and that is going rather far, because I think luminaires create no problem. The sky out-of-doors is much brighter than that. So, if you want to worry about degenerations, the poor farmer who works outside is the one you want to worry about, not the office worker—unless he wears sunglasses and most of them do not.

To summarize, I do not believe anybody really has any reason for concern under around twenty thousand footlamberts. I talked to your man Palmer; he agrees with this point. I talked to Sperling; he agrees with this point. Twenty thousand, somewhere around there, is the first point at which to be concerned. Nothing in an interior environment is of that high luminance. So I think, truly, this is a bit of a tempest in a teapot.

Dr. Riegel: Is that for continuous exposure?

Dr. Blackwell: Yes, right. Sperling exposed them for days.

Dr. Weale: We are concerned about years, are we not?

Dr. Blackwell: Not without breaks in the cycle. Who stares at a luminaire for twenty years of his life without shutting his eyes?

Dr. Halldane: This is a relevant topic, because you can get reflected luminaires in glass windows and things like that. It is very important, because you are getting greater contrasts if you take out lamps under conservation programs. You are intensifying some of the contrast problems and they are some of the proposed conservation programs by GSA.

Dr. Blackwell: Of course, if you bared the tubes to save light, then you would be doing the most dangerous thing.

Dr. Halldane: In some cases, this could occur, with lack of sufficient guidelines, in an energy conservation program. So we are trying to consider, in this symposium, these sorts of contingencies, surely. Now, the Australian and British codes have limitations on the luminances of lamps, which is a very vital thing to include in the American guidelines that may be developed. And this will answer, I think, the concern and problems that are being generated by people who are concerned with the glare problems of higher luminances in the visual field. This is not an irrelevant problem because it should be identified as a significant problem of lighting in future guidelines and particularly under conservation programs.

Mr. Crouch: In the United States, the IES also recommends limitations on the luminance of certain lamps. It is two hundred and fifty footlamberts for large areas, and, for smaller areas, it is larger. But it will never exceed about a thousand footlamberts.

Dr. Halldane: It is ten candela per inch square in the Australian standard.

Dr. Blackwell: That is fourteen hundred forty candles per square foot.

Dr. Cogan: Dr. Tso is interested in the practical effects of indirect ophthalmoscopy damage to the eye. So he exposed the eye for one hour, perhaps to see if ophthalmoscopy does damage the eyes.

Mr. Crouch: Well, he reports, too—and I read you the journal, *J.A.M.A.*, where he reports that this applies to light.

Dr. Cogan: Right.

Dr. Blackwell: He is the one who went beyond—

Mr. Crouch: He went on to extrapolate.

Dr. Cogan: : It is the indirect light that he is using; that is the one that he is interested in.

Mr. Crouch: Good lighting in the interiors, he goes on to that in the journal. Here it is: "Long, well-lit lives may lead to eye damage." And he tells the science writers, "the Research to Prevent Blindness (RPB) Science Writers' Seminar in Los Angeles about work with twenty-four rhesus monkeys."

Dr. Cogan: Was that not indirect ophthalmoscopy that he used?

Mr. Crouch: He said it applies to lighting, ordinary lighting.

SOME NOTES ON PHOTOMETRIC UNITS

AND AN ABSTRACT ON BEHAVIORAL PERFORMANCE CRITERIA

John F. Halldane, Ph.D.

Chairman Heins: Our next speaker is Dr. John Halldane. Dr. Halldane has agreed to briefly review the basic measurement concepts of lighting and to emphasize the salient points in his abstract. (A summary of Dr. Halldane's comments and a copy of his abstract are presented on the following pages).

Some Notes on Photometric Units

Dr. Halldane: Before we discuss the merits or shortcomings of any lighting we must be sure that all the measures we use are understood.

Electromagnetic radiant power, P, measured in Watts (W), is based on thermal flow.

Light is radiation that can be seen, either by scotopic or photopic vision. Wavelengths of radiation $\lambda400$—$\lambda556$—$\lambda800$ nm is visible range. Note that plant photosynthesis is more effective about $\lambda500$ and skin absorption about $\lambda800$—$\lambda1,000$.

Luminous power is light assuming photopic vision. The measure is a lumen, lm, which is equivalent to about 680 lm/W at $\lambda556$. An instrument simulating visual responses must be photopically corrected with a **filter.**

Luminous power passing through a unit area or power density, E, is illuminance for incident light. Units—

BRITISH	METRIC
lm/ft²	lm/m²
footcandle (fc)	lux (lx)

1fc = 10.76 lx

Note that the meter must be **photopically** and **cosine** corrected.

Illuminance has **no** direct correlation with a visual response. It can be shown that the luminance x visual area can relate to the illuminance **on the pupil** of the eye.

Luminous Intensity, I, is the light passing through a unit solid angle. $I = P/\omega$. It only relates to a **point** source of power and has no direct correlation with responses. Units are lumen/steradian (lm/sr) and the candela (cd).

Luminous planar intensity or luminance, L, for light from a surface. This is the orthogonal (at right angles) luminous intensity density measured in

BRITISH	METRIC
cd/πft²	cd/m²
footlambert (fL)	nit (nt)

1fL = 3.43 nt

$L = I/A\cos\Theta$

where A = surface area
Θ = angle from normal

Luminance correlates with the visual response of luminosity (apparent brightness, brightness). It can be measured with a telephotometer. The filter and lens system simulates those aspects of vision but not the adaptive and contextural effects. A luminosity response varies as the 0.2 power of the luminance in our design ranges. Standards and performance specifications should always be stated in luminance measures as they relate directly to the human response—luminosity, the magnitude of a color.

A **special case** when the surfaces are **perfectly diffusing** and have a reflection factor or reflectance, K

$$L\ (fL) = K_{reflection} \times E\ (fc)$$

Note the qualifications to this simple expression.

Units in "energy" conservation

Energy (Q)
Joule (J)
1 Btu = 1.052 kJ
1 Therm = 105.2 MJ

$$\text{Power, } P = \frac{dQ}{dt}$$

Watt (W)

1 Btu/hr = 0.2922W

Everything should be converted to the SI metric system for a convenient comparison.

AN ABSTRACT ON BEHAVIORAL PERFORMANCE CRITERIA

Dr. Halldane: There is a growing controversy over what "lighting levels" should be adopted. The political camps are divided; on the one hand, for a universal lowering of task illuminance to meet the demands of power (energy) conservation and on the other, a raising of illuminance to improve visual detection or visibility performances. Government agencies are charged with undertaking conservation measures while maintaining peoples' health and safety. Organizations such as the Illuminating Engineering Society hold themselves responsible for the improvement of lighting systems to the benefit of mankind. My belief is both directions are needed but that more attention should be paid to the lighting design for various visual responses and not to become preoccupied with illumination alone since illumination does not directly relate to human responses.

Conservationists are concerned that lowering illuminances will cause eyestrain, accidents, and errors in responses. Previous minimum codes or recommendations reflected from past lighting experience (Australia's Standard No. C.A. 30–1957—Artificial Lighting of Buildings), were roughly half of what they are now and many other countries still have those criteria. People performed satisfactorily in the past under those conditions and are likely to continue to do so with similar task difficulty. For general activities of moving about buildings, recognizing people, reading signs, and writing, the visual tasks are not demanding. Consequently, a conservative lighting system would be satisfactory. Just decreasing lighting by taking out lamps is not a sufficient consideration alone. The familiar recessed ceiling luminaire is very inefficient in that the ceiling is not illuminated directly. This creates strong contrasts with the diffuser. Previously, and in other countries, luminaires projected below the ceiling or were suspended from it to overcome those difficulties. Substituting reflectors for lamps would increase the luminaire efficiency by about 10% and reduce the glariness caused by the shadows of disconnected lamps under half fluorescent lighting programs.

Clarity of visual forms is important in environmental assessment. This depends on the luminous gradients and the related blur response in the visual field. The function does tend to peak with increasing luminance, particularly in the lower "conservation ranges", and the National Bureau of Standards is studying this. Say NBS does find a maximum range, the response would be appropriate for assessments concerning the formal articulation or clarity of a space but it would not preclude the consideration of visibility in detection-like tasks. An answer here depends on the design goals. In equal interval luminosity (brightness) scaling experiments (Halldane 1968), varying surround lightness and illuminances between 10-90 fc produces the least distortions and variances than outside this range. In another way, the least perceptual variations in viewing the grey Munsell Value color scale against different surrounds would be with illuminances of 10-90 fc. Thus the formal molding and textures of a space become more consistent and clearer. At lower levels, the scale tends to merge into darker tones; at higher levels, into lighter tones.

Visibility of detection-like tasks has been clearly demonstrated by the Blackwells and others to increase with illuminance. With older age and the increasing demand for detail nowadays in specific visual tasks, this concern is justified. My argument is that the general lighting of spaces should not be expected to provide the higher illuminances for the detailed tasks. There are various control systems for resolving the problems including worn, fixed, or portable lenses; luminaires proximate to the task surfaces like desk or reading lamps; more contrasting stimuli; daylight; magnifiers; larger print; lamp shielding; TV image enhancement; and equipment to avoid detailed tasks like a needle threader, etc. There is considerable scope for innovation. It should be remembered that the limiting criteria are based on the luminous visual field impeding the activity, such as the photic, flicker, phototropic, after image, pain responses.

The significant concept in evaluating behavioral problems is that it can not be based on one parameter alone or a single behavioral response. It is not a matter for compromise but rather a satisfaction within limiting criteria for each of the evaluative parameters according to their intended design goals.

LIGHTING, PERFORMANCE AND AGE VARIATION

R. A. Weale, Ph.D., Sc.D.

Dr. Weale: I want to talk as briefly as I may about some of the physical aspects of the eye, aspects which will make you wonder without any question whether it would not be wiser to consider units of luminance rather than illuminance, which have been so carefully distinguished by Dr. Halldane. When I want to concern myself with senile changes in the eye, then, as I say, I want to deal primarily, though not exclusively, with physical aspects, and that means with the ability of the eye to utilize such light energy as is capable of reaching it. It means a sine qua non. It means, as I hope I will show you, that no matter what we do, what levels we decide as being suitable for the eye in general, certain compensations will have to be made for senile changes which have been observed throughout the years in all of us. I am very conscious in this that one depends, to a large extent, on average data. This has severe drawbacks, especially insofar as establishment of casual relations is concerned. But we will come to that later.

By way of introduction, allow me to show you a section through the human eye. This is a schematic section through the eye which illustrates some of the salient points which distinguish an old eye from a young eye. I want to concentrate on two. This opening is the black of the eye, the pupil; and you will notice that it is smaller in the old half, which is shown down below, than in the young eye. It is a matter of common observation that the old pupil is smaller. This has been called senile miosis and is almost certainly due to the fact that the muscle which dilates the pupil atrophies at a faster rate than the muscle which constricts it. Consequently, the constrictor wins and the old pupil is smaller than the young one. None of this throws any light, any information on how easily the pupil constricts. In fact, contrary to conventional wisdom, it can be shown that the old pupil is more mobile than the young one.

The second point I want to stress relates to the lens. I do not want to bore you with details relating to the size, which I indicated here; but I do want to bore you with a very important point. Namely, the fact that the older lens is shown darker than the younger one. To cut a long story short, the older lens transmits less light than the young one. This is important and does not take into account that the older lens may, and in many cases does, scatter more light than the young one. Even if there were no change in the scattering properties of the lens, you would still find that, as though there were an increasing density in some gelatin filter, the old lens transmits less light. In addition to this quantitative change, this reduction in the light transmitted, there is a qualitative change in the sense that the increase in density and absorption predominates at short wavelengths. So, while we get a reduction in transmissivity of the lens as a whole, this is dominant at short wavelengths; in other words, in the blue and violet part of the spectrum. Well, so much for the setting of the scene.

The next slide (Figure 1) shows one slightly different from that shown by Mr. Crouch a little earlier and shows the distribution of visual acuity plotted on a decimal basis along the ordinate—that is the more conventional basis here, along the five meter basis—as a function of age. Umpteen distributions of this sort have been published. It really depends on how you select your patients. You can be pessimistic like Mr. Crouch and get a diminution which extends more or less throughout adult life. Or you can be more optimistic as the authors of these papers were and you can show that, if pathological conditions are absent, visual acuity is preserved up to about fifty and then starts decreasing at various rates. Now, the photometric points which I mentioned earlier—namely, the reduction in

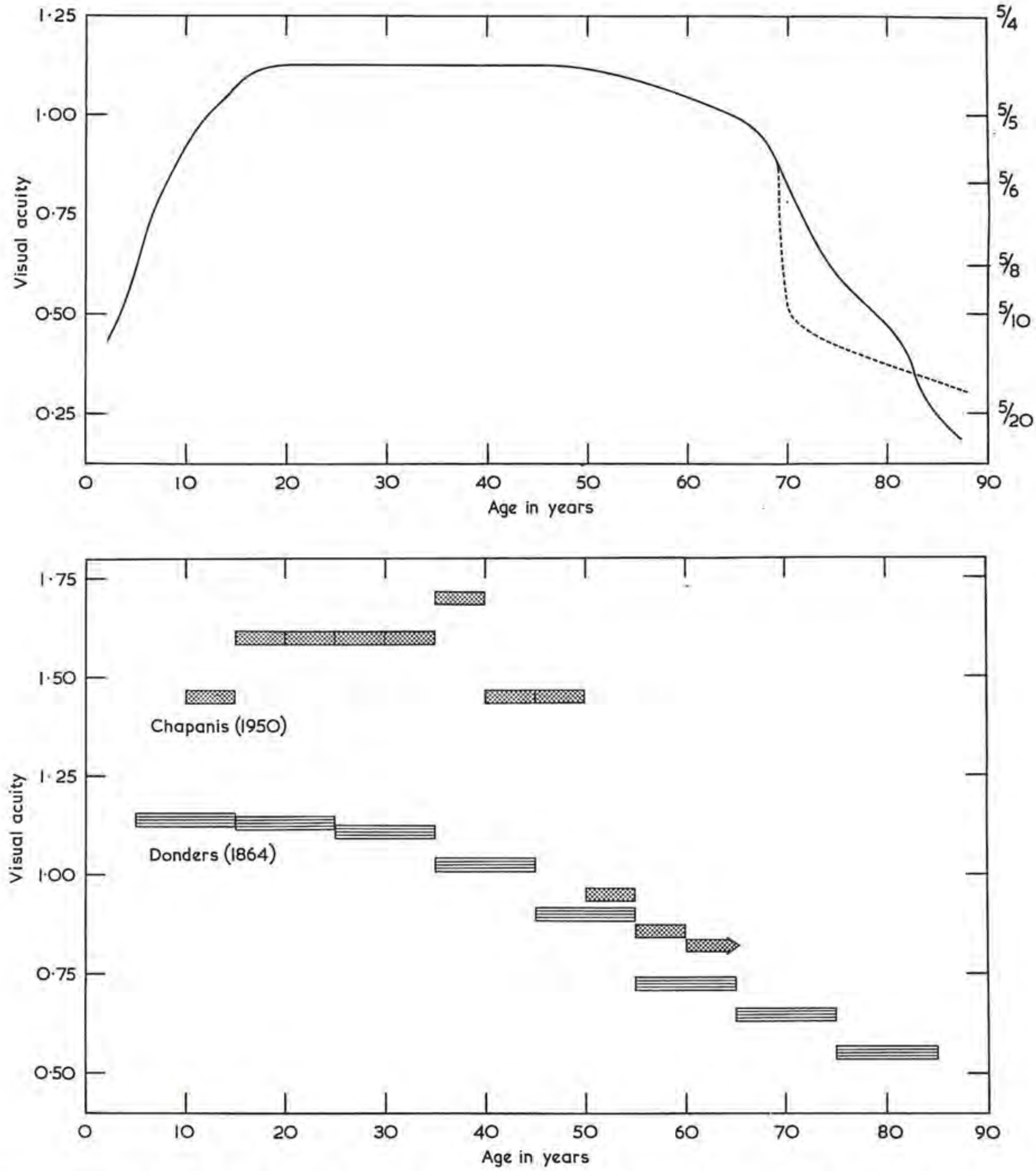

FIGURE 1.—Variations of visual acuity with age. Slataper's data (top) were collected probably under better conditions of illumination than were those due to Chapanis and Donders. (For details, see The Aging Eye, R. A. Weale (1963), H. K. Lewis, 179 Gower St., London W.C. 1. England.)

the diameter of the pupil as we get older and the reduction in the light transmitted by the lens—necessitate that, for an equal retinal performance, we have to make up the loss entailed in this case and in this simply by increasing the amount of light sent into the old eye, both insofar as pupillary area is concerned and—to add a qualitative factor—insofar as the spectral distribution of the light is concerned. If you want to look at things purely from the physical point of view, it is absolutely inevitable that these deficits ought to be made up. Now, before we get too alarmed, let me stress that, as far as I am concerned, I think this problem arises seriously only under threshold conditions. It is only where you have light available in such small amounts and, for example, in the proverbial corridor, or where light is available merely as a safety measure, for example, in photographic departments and so on, then, in my view, you have to compensate for this. Normally, the amount of light present is such that a correction due to this factor can probably be overlooked. And the new code, which you allowed me to mention this morning, used by the British Illuminating Engineering Society no longer distinguishes between the light requirements between older and younger workers, the idea being, as I mentioned earlier, that the amount of light needed to do the task shall be determined more or less in loco.

There are some data here which also have bearing on something Mr. Crouch mentioned and they relate to the differential, the incremental sensitivity of the eye as a function of age. The data here are plotted as sensitivity, not as threshold, and are expressed as ratios of the reciprocal of the incremental intensity to the field intensity along the ordinate and age along the abscissa. And the important point, I think, which these data show, is that, in the absence of glare, the decrease in sensitivity as a function of age is only about twenty-five percent over the range shown; whereas, note that it is very much more appreciable where a glare source is present. It seems to me, therefore, that one way of improving the photic environment of the older worker is by minimizing the number of glare sources of intensity present in their visual field.

There is a correlation between the data shown in the previous slide and this slide which shows the number of defects, ocular defects, as a function of age—or rather the probability of your suffering a defect. You see, by the time you come to seventy, the chances of you suffering from some trouble or other is ninety-two percent.

Mr. Nelson: Is that over and above these aging characteristics?

Dr. Weale: This is an unselected population.

Mr. Nelson: Yes, but I mean are you talking about defects other than the aging characteristics?

Dr. Weale: Yes, that is right. Since the other conditions, on the average, occur in everybody, they ought to be considered as physiological as distinguished from pathological. I think these cases are pathological, precisely because they do not happen to everybody.

Now, you can produce a good fit between this curve and the rather scrappy data which I showed in my previous slide. And people have suggested that, small wonder, more and more goes wrong with the eye. So your incremental sensitivity is reduced where your incremental threshold rises.

Mr. Crouch: I wanted to ask about a previous slide. Without glare, would this be a uniform brightness background or no background?

Dr. Weale: No, there must be a background, because there is a "B."

Mr. Crouch: I meant the surroundings.

Dr. Weale: I do not remember the exact experimental details, but it involved an incremental measurement.

Dr. Blackwell: If the field was large, you have stray light in the uniform field, which amounts to seven percent in the young and twenty-one in the old.

Dr. Weale: I will grant you this; but, from my recollection, this involved a separate glare source, whereas the data on the right did not.

Dr. Halldane: Was that surround or peripheral?

Dr. Weale: A peripheral source, yes.

Dr. Halldane: So it was basically entoptic scatter which influenced the contrast.

Dr. Weale: That is right, but it was focal scatter, a focal source, if you know what I mean.

Dr. Halldane: Okay.

Dr. Weale: It does not follow, necessarily, that there is a causal relation between these data and the results shown in the previous slide, because Voss showed, for example, that a result such as this has to receive careful statistical attention. He measured incremental thresholds and light scatter, I believe, by photography of the lens in a large number of observers. Although, statistically, there was an increase in the scatter and in the threshold as a function of age, when you compared the data obtained for each observer, the correlation that emerged was the sort of thing that you get if you correlated the color of hair, gray hair or baldness, with age. It did not follow that the two were related causally; and I think the same caveat has to apply to these results here.

One other result I think that ought to be mentioned, and that relates to the speed with which the eye reacts. The reaction time, as it is called, which is plotted here along the ordinate, and, again, age along the abscissa, with the number of observers shown with various symbols. You see then that there is a general rise in the higher age groups. The system appears to react more slowly. Well, these values are only fractions of a second, but it seems to me that they illustrate a point which it is worth making in connection, for example, with visual performance. It is not enough to consider the physical requirements which we have to meet as a result of the factors which I mentioned; namely, the pupil and the lens. There is what Dr. Blackwell might refer to as a field factor or what I would, perhaps, more likely refer to as a jog factor. Older people have to be jogged along, encouraged along, need a stronger stimulus, perhaps because it takes them longer to make up their minds. This is, of course, one of the hazards. This is one of the reasons you get accidents in the street. When older people cross the road, they do not know whether the car is far enough or not. They can see it; the visual part of the performance is accomplished. It is the decision which may need a reinforcement of the stimulus.

Mr. Nelson: What are you categorizing as older people, I am wondering?

Dr. Weale: Those that are not younger.

Mr. Nelson: I am trying to superimpose the normal retirement age across your graphs because I am interested in a working population, and I am just wondering whether the person who is casual in the street, incapacitated in the street, I usually think of as postretirement age. And I am just trying to determine whether we are talking about a total population or a total population subjected to working conditions. The different researchers seem to disagree rather widely on that one.

Dr. Weale: I, for one, am not going to be tied to any averages. I may use them, but I am not going to be tied to them, because I do not think they exist. But, of course, for the purposes of graphic presentation, they are a sine qua non. You see here we have a marked rise in the sixth decade. You may say that these data are not representative; but, of course, there is a tendency for a rise in these data as well. And you can put it operationally: you are old when you can not make a decision. And this may differ in various walks of life. Financially, it may happen pretty early in life. When it comes to crossing the road, it may happen a little later. When it comes to certain tasks which require decisions, it may very well happen in the fifties. I do not think we can really say that a person is old for a task if we confine our attention to his biological age. I think it must be accepted—I was turning gray at twenty—that there are various indices of age; and, whenever an index involves a difference in something that by common consent is referred to as young, in this particular respect, the person is old. That is why, if you will allow me, I would rather not generalize on this particular point.

When all is said and done, the results shown in this particular slide can, with confidence,—or such confidence as we can muster —be referred to only to the criterion which was used in order to arrive at them. Whether we are going to extrapolate from these data to other tasks altogether depends on the decision which we have to make.

These data refer to so-called dark adaptation curves which were also partly referred to by Mr. Crouch. They have a bearing on, again, threshold conditions. I know that this relates to a level much lower than we are contemplating, not to reduced but to very low conditions. It seems to me that we have to stress the physical aspects of a performance which depends on faulty conditions. I have only brought them along to show that, although it is commonly said that older people dark adapt much more slowly than young ones, what we mean by that is that, if a different level of illumination is, say, where I put it here, then, if people have been exposed to bright light, it will take them longer to reach this criterion than if they are young. The fact of the matter is that, to a large extent, you can account for these differences purely and simply in terms of reduced pupillary diameter and increased light absorption of the lens which older people suffer from. In other words, under conditions where there is no effect, no evidence of any pathology, the only effect which hinders vision in older people is attributable directly to the physical factors which I mentioned; namely the transmission of the lens and pupillary diameter.

Dr. Blackwell: Do you think more than a hundred to one can be explained that way?

Dr. Weale, Well, oddly enough, this was obtained with violet light, and the . . .

Dr. Halldane: Oh, no wonder, that is much lower (and slower).

Dr. Weale: We are talking about the rod section here, and you are dealing with people who are getting on toward ninety; and this is where you put two log units—

Dr. Blackwell: It is more than that.

Dr. Weale: Yes, but I said the major part. Alright? The major part of this difference is attributable to changes in the lens.

Dr. Riegel: Is what you said equivalent to saying that, if you regard that family of curves as a set of decaying exponentials, that the same time constant is associated with each one?

Dr. Weale: To a first approximation, I will produce evidence to support that in a moment.

Dr. Blackwell: Would you agree that, also, there is a degeneration of photoreceptors?

Dr. Weale: There is no evidence of that. I would like to know about it if there is.

Dr. Blackwell: I thought Ernst Wolf showed that.

Dr. Weale: I am not aware that he looked at photoreceptors. Did he?

Dr. Blackwell: Yes. He said there was a deterioration, a loss of photoreceptors.

Dr. Weale: But Wolf was a psychophysicist. I am not aware that he has done any histological studies.

Dr. Blackwell: He delved into this. I have the paper.

Dr. Weale: Well, I would be very interested and grateful to have this.

Here you have summarized data showing the reduction in the pupillary diameter, both in the dark-and light-adapted eye as a function of age. And, using these data, of course, one can predict how the light requirements of the eye are going to change as a function of age. And, similarly, here, you have measurements for the light transmission of the lens obtained by a variety of workers as a function of age. And here, again, these data can be used to predict the changes which you would expect in basic visual functions.

And here (Figure 2) you see one example of the fulfillment of this prediction. The threshold of vision is plotted along the ordinate here as a function of age and shown by these dark rectangles. The data which I have shown you in the last slide relating to the pupillary area are shown by the light oblongs. And you see that, to a first approximation—not wholly, I agree—this data can be explained in terms of senile miosis. Let me stress that the threshold here, contrary to the data which I showed you a little earlier, was measured with white light, in which case, the changes in the transmission of the lens would not play a primary role.

Here there are some data obtained by Gouras and Gunkel. These were obtained for normal observers, normal subjects as they would be in this case—no, they are observers —and they are shown with these white symbols; and then some people who had lost their lenses, with aphakic eyes, shown with circles. Now, the point which this illustrates is this. Those, of course, who have their lenses intact will experience the sort of yellowing, the increase in absorption that I have mentioned; and, as you get older, you need more and more light to compensate for the light absorption of the media. Consequently, the violet threshold will rise pretty appreciably— there you are, Dr. Blackwell, two log units— over the age spectrum. On the other hand, the aphakes—and look, there are quite some young ones amongst them—are virtually horizontal. You see, there is hardly any change at all in the violet part of the spectrum. Similarly, since the crystalline lens does not absorb much red light, you would expect a very much smaller change in the red part of the spectrum. In fact, this is parallel for both the normals and the aphakes insofar as one can judge from these results. White light, of course, is of practical importance and, as I mentioned a little earlier, for white light, as such, one has to make some allowance; but it is not very, very critical. Well, you see from this, my contention that the lens is responsible for visual performance, especially in the short wavelength part of the spectrum, is supported to a considerable extent.

Of course, one asks oneself whether the changes can account for other visual functions. By way of example, I have brought along Weeker's data, who compared the fusion frequency as a function of age when the pupil was both natural and dilated. And you see that there is prima facie evidence for the suggestion that the fusion frequency, which we know is reduced when the retinal illumination is reduced, is reduced, to a considerable extent, by senile miosis.

Well, all of this can be summarized very glibly but, perhaps qualitatively, in my last slide where we show the amount of light, not

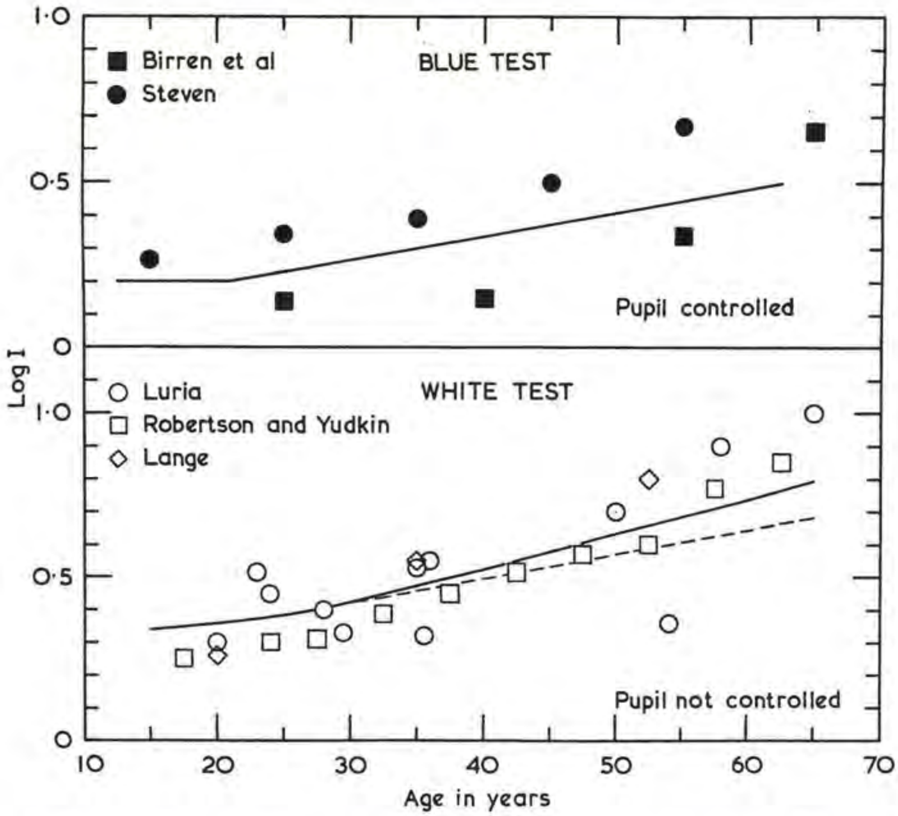

FIGURE 2.—Ordinate: Log visual threshold in arbitrary units. Abscissa: Observer's age. Top: Measurements obtained with a blue test-field and an artificial pupil. The line shows the rise in threshold expected on the basis of the senile rise in the density of the crystalline lens. Bottom: Measurements obtained with a white test-field and natural pupils. The dashed line shows the rise in threshold expected on the basis of senile miosis, and the full line the rise expected if, in addition, the senile rise in the density of the crystalline lens is also considered. (The Aging Eye, see reference figure 1.)

reaching the eye, but getting through to the retina as a function of age under photopic and scotopic conditions. The photopic conditions are shown with the light circles and the scotopic with the dark ones. Along here, we have considered only the lens and here we have considered the lens and the pupil. You see that, as a rough and ready measure, one can say that the eye at sixty needs about three times the amount of light which is needed by the eye at twenty, under threshold—that is under physical—conditions, without taking into account what might be needed at higher levels.

Well, it seems to me worth stressing this because I feel that, if we are going to get involved in reducing levels of illumination, we should, on the one hand, be reassured about what can and cannot be done for old people, and, on the other, remember that any appreciable vital amounts of light which old people may need are probably available because we are working well above threshold. Thank you.

DISCUSSION

Mr. Caplan: Dr. Weale, did you have any indication as to the reason for this change?—Was it strictly a presbyopic type of thing or was it as a result of exposure to something or what causes this change? Or is it the circulatory effect that was mentioned earlier?

Dr. Weale: I am sorry, which change are you referring to?

Mr. Caplan: The requirement of three times as much light to perform the same task for a sixty-year-old compared to a twenty-year-old. What causes that?

Dr. Weale: Well, I think this is due to two changes. On the one hand, you find that smooth muscle tends to atrophy; and, in the case of the pupil, its size is governed by the interaction, or we might say antagonism, of two types of muscle, the pupillary dilator and the pupillary sphincter. My view, for what it is worth, is that the pupillary dilator atrophies at a rate faster than the sphincter. It simply loses its function at a considerably faster rate. This means that the sphincter wins. In the young, they work against each other, but in the old there is no antagonism.

Mr. Caplan: Is this a normal function?

Dr Weale: This is normal, yes. I can not buttress this with great force because, believe it or not, as far as I know, there have been only three investigations since 1923 dealing with the senile histology of these muscle fibers. I think what I am saying is reasonable, just for once. As regards the lens, the lens is a very peculiar tissue, as is, of course, obvious. It has no blood supply. It has great difficulty in getting rid of its waste products. Moreover, as I indicated in my slide but I did not want to draw your attention to other problems, it goes on growing throughout life. It keeps on laying down layer after layer. There seems to be no halt to that. Well, this is also a problem; and the upshot of all this is that the inner layers are subjected to greater and greater pressure, to an environment which you can not really call biological any more. You get waste products; they do not know what to do with it, so the layers change color.

Mr. Caplan: It is not an external environment.

Dr. Weale: It is not the external, it is the internal environment, or rather the lack of an internal environment, which I think is primarily responsible in the case of the lens.

OCULAR DISCOMFORT AND OTHER SYMPTOMS OF EYESTRAIN AT LOW LEVELS OF ILLUMINATION

Glenn A. Fry, Ph.D.

Dr. Fry: After Dr. Cogan's presentation, I probably should make some apologies for using the word eyestrain.

However, he appears to be willing to talk about asthenopia, which is another name for eyestrain, and is objecting to the word strain because it conveys to the public the notion that low illumination hurts the eyes. When Dr. Cogan says that low illumination does not hurt the eyes, he means that no organic disease results from low illumination.

The concept of eyestrain is widely used in optometry and, I thought, also widely used in ophthalmology. And I came, as a matter of fact, deliberately prepared to demonstrate that there really is no difference in approach to the problem by these two professionals. I want to call your attention to a chapter on eyestrain in Duke-Elder's *System of Ophthalmology, Volume* 5. It describes in great detail all about eyestrain. So there is really not much in my commenting about the subject. There is also a similar chapter in a textbook widely used by optometrists called "Clinical Refraction" by Borish which covers, in a similar way and thoroughly, the subject of eyestrain. Furthermore, I came prepared to demonstrate that it was not discovered yesterday because a very adequate discussion of the whole subject appeared in Donders' *Anomalies of Accommodation and Refraction of the Eye* in 1864. He called it asthenopia. The term, asthenopia, had been coined by Mackenzie in 1843. Donders traced the history of the subject all the way back to the Greeks.

I would like to outline for you the aspects of the subject I want to cover.

First of all, we have the sequelae, or symptoms, of eyestrain which are pretty well defined. And then we have the mechanisms of producing eyestrain. And then we have the problem of relating it to discomfort and showing, also, how it is related to the problem of lower levels of illumination.

Let me just read a portion of Dr. Lancaster's account of eyestrain which will take care of the subject of the sequelae or the symptoms. The author is referring to eyestrain from faulty illumination.

> The term eyestrain is used in its broadest sense to cover all forms of ocular discomfort and associated symptoms. What are the symptoms? They may be classed under three headings
>
> A. Local Irritation.
>   1. Sandiness, a conjunctival sensation. It includes hot, itchy, scratchy, dry feelings.
>   2. Tired, aching, painful feelings in the eyeball, orbit or head.
>   3. Blurring of vision.
>   4. Eye inflammation.
>   5. Photophobia.
>   6. Red and swollen eyelids, which may amount to blepharitis.
>
> B. Headaches and fatigue of various sorts.
>
> C. More remote and indirect symptoms, including vertigo, digestive, and psychic reactions.

Eyestrain and all of the symptoms associated with it arise from the effort of the subject to keep his eyes adjusted for seeing. These adjustments include fixation, convergence, accommodation, and control of the size of the pupil.

Let me move on to the mechanisms involved in eyestrain. I want to review briefly the structures in the eye, orbit, and brain related to eyestrain. Consider a front view of the eye.

First of all, we have the cornea, which is imbued with good sensitivity to pain stimuli; and this is a part of the whole syndrome of eyestrain. Many of the symptoms can be produced just by putting a chemical irritant into the eye; for example, if you get soap in your eye when taking a bath, you can get a smarting sensation. In a front view of the eye, you see the pupil of the eye and the iris. The muscles in the iris control the size of the pupil. The sphincter, in particular, is a source of discomfort; and discomfort increases in the case of iritis when the pain sensitivity is grossly increased.

The lids of the eye contribute to discomfort because they are involved in the experience of tension. This tension includes also the extraocular muscles and the so-called accessory muscles around the margin of the orbit and up on the forehead and even to the back of the head. We speak of redness of the eyes. This involves the injection of small blood vessels that come out over the surface of the sclera.

Going back into the orbit, we run into some other mechanisms. One is the lacrimal gland. Tearing is often referred to as one of the symptoms of eyestrain. It comes pretty late in the syndrome.

Going one step further back into the orbit, we see the extraocular muscles which are involved in pointing the eye in a given direction and are also responsible for coordinating the directions of the two eyes. The muscles of the eye are producers of pain, as can be demonstrated by simple application of increased tension on these muscles as is possible in the operation of a patient. It can be demonstrated on the actual human subject.

This brings us to the interior of the eye and we are interested here in the ciliary muscle and the iris, or the sphincter of the iris. We see them best in a cross-section. These are mechanisms that are involved in adjustment of the eye to its environment; and unusual effort will result in symptoms of eyestrain.

The ciliary muscle controls the shape of the crystalline lens inside the eye which makes it possible for the eye to change focus from objects at one distance to objects at a different distance. This is called accommodation. In looking through a screened window at a distant object, one can focus on the screen or the distant object at will.

There is a problem about whether the eye can tell ahead of time whether it needs to increase or decrease accommodation or whether it operates on a trial and error basis. There is not complete unanimity on the mechanisms involved, but this is one of the adjustments that may involve the conscious effort of the subject. It may become somewhat subconscious as in lifting your hand to your mouth in the process of eating; but, nevertheless, it is a thing which is subject to voluntary control.

In uncorrected hyperopia or presbyopia a large amount of the total accommodation possible may be brought into play and this may lead to discomfort and eyestrain. Donders thought that this was the major factor in eyestrain but there are other factors.

There is also the problem of astigmatism which may result in recurring shifts in the amount of accommodation in play.

Fortunately optometrists and ophthalmologists can eliminate these sources of eyestrain by prescribing glasses.

Now, we also have the problem of rotating the eyeball around its center of rotation, and that constitutes another adjustment which we call fixation. There is also the problem of keeping the two eyes trained on the same object, which is the fusional process; and that is quite distinct from the fixation process.

The problems of accommodation and fixation are things which can be demonstrated with one eye. If you want to differentiate between eyestrain associated with binocular vision and eyestrain associated with just a single eye, all you have to do is simply cover one eye with an occluder. It is a simple test that is used to isolate the source of eyestrain or discomfort.

The fusion process is a reflex process which depends upon inputs from the two eyes that are transmitted to the cortex and there has to be some interaction between these two inputs in order to point the eyes in the same direction. In spite of the fact that it is reflex in nature, the demands made upon it can be excessive and this leads to discomfort and eyestrain.

The pupillary response to light is also a purely reflex affair. If we have intense glare sources in the field of view, the contractions of the pupil will produce discomfort. And, strangely enough, the discomfort is followed by a sequence of symptoms. You get a gross discomfort and then you get a feeling of tension and, finally, you get blinking and tearing. This is characteristic of various types of eyestrain.

The mechanism for accommodation is connected to two other types of response: (1) a response of the pupil, which is a different type of response from the light response, and (2) a response of convergence. And, when I first came into this field forty years ago, we knew that there must be a cortical center for the control of this group of responses. Since then, Jampel, who is now head of the Ophthalmology Department at Wayne State University, has discovered such a center, electrical stimulation which will produce, simultaneously, these three types of responses. This triad of responses is subject to voluntary control. One can use this triad mechanism to change convergence, accommodation or pupil size. One can watch his own pupils with a pupillometer, and use the triad mechanism to demonstrate changes in the pupil size. You can regulate it as finely as you want.

The pupil response associated with accommodation and convergence which is voluntary must not be confused with the light reflex which involves a different mechanism. You can watch a diplopic image and regulate the convergence of the eyes, or you can use the clearness or sharpness of the retinal image to control the accommodation. You use the same motor mechanism and get all three responses in all three instances. Now, strangely enough, the triad response does not usually involve eyestrain. If you carry it to its limit, one can get a painful end-point nystagmus at the near point of convergence; but, generally, the use of this mechanism is free from discomfort.

And the same thing applies to fixational innervation. You can voluntarily pull your eyes to the right or left or up or down to the limit and produce a painful end-point nystagmus.

A one-eyed man who can voluntarily fixate and accommodate is usually a comfortable individual.

The mechanism of fixation is such that, when one makes an attempt to fixate a given point, it is not a steady process and the eye is continuously shifting and drifting from one position to another. Now, I think some emphasis has been placed on the work of Hebbard as having demonstrated that this lack of precision in fixating a given point is dependent upon the level of illumination. I want to point out that this is not the kind of thing that we would expect to lead to eyestrain or discomfort. It may affect performance, but we do not associate it with discomfort. I do not recommend it as an approach to the problem of trying to get a measurement that you can correlate with the symptoms of eyestrain. Incidentally, Dean Hebbard is dean of my college; and I have brought along copies of a couple of his papers that have been referred to. If any of you want a reprint of his work, they are available.

There may be some of you who are interested in his method of measuring eye movements which involves the use of no appliance applied to the eye, no contact lenses, nothing but a beam of light. But it does have a great deal more precision than the ordinary method involving photographing the corneal reflex. It would represent a very useful auxiliary in making measurements of fixation and fixation disparity.

When we are using the two eyes, we have to differentiate between changes in fixation and changes in convergence. Now, changes in convergence can be induced by changing the distance of the point on which the eyes have to converge, or we can introduce a prism over one eye. If we want to change accommodation, we can change the distance of the target, or we can put plus or minus lenses in front of the eyes. Changes in accommodation can be induced while one eye is covered; convergence requires two eyes.

In optometry and ophthalmology, we measure what we call the phoria position. This is the position of rest that the two eyes assume relative to each other when one eye is covered or when there is no target in the field of view on which they must converge.

There are three ways in which the eyes can fail to converge at a point at a given distance. The one eye can turn up or down with respect to the other (vertical phoria); the one eye can turn in or out with respect to the other (horizontal phoria); the one eye can be rotated around the line of sight with respect to the other (cyclophoria). When both eyes are uncovered and confronted with an object, they have to overcome the phoria problem by correcting the horizontal and vertical vergence errors and by cycloverging. These adjustments have to be maintained and, as I indicated earlier, are reflex. If the phoria error is large, a great deal of effort is required to maintain fusion and this can lead to the condition of eyestrain, with all the symptoms of eyestrain.

I have grossly simplified the problem as if all the eyes ever had to do is converge on a single point and cyclorotate to line up the right eye and left eye images of a single line.

Suppose we have two points or a cluster of points. Then we have to worry about aniseikonia which is a difference in the size and shape of the images in the two eyes. These differences primarily disturb space perception, but, also, they lead to a complicated fusion problem because the two eyes can adjust themselves to fuse on a strong stimulus in the periphery and have difficulty maintaining fusion on a small target presented to the two foveas.

If a person has to look at a pattern involving vertical and horizontal lines such as a square, the image formed by the eye may be a perfect square but the image formed by the opposite eye may be distorted into a diamond shaped quadrilateral. The eyes may fuse one set of lines but not the other. Looking at a printed page can involve difficulties of this sort, which will lead to discomfort.

A majority of patients who come to an optometrist for an eye examination do so because they think new lenses will help them see better, but a significant number come with the complaint of discomfort or fatigue when they use their eyes. The optometrist looks for various sources of the discomfort but is seldom able to say that this or that is the specific cause. He can usually decide on a pair of new lenses which will correct the refractive errors and other anomalies. Sometimes the glasses are supplemented with training designed to eliminate anomalies that cannot be corrected or compensated with glasses. The procedure is more like a general overhaul rather than a determination of the specific cause of discomfort. Good lighting will always be recommended because, if there is difficulty in getting the eyes adjusted for comfort, poor lighting will make the situation worse. It is not very likely that a given optometrist would ever guarantee that a certain level of luminance is the lowest that will permit comfort.

The things that an optometrist will check routinely in looking for possible sources of discomfort are as follows:

1. Refractive errors.
2. Balance in the amount of accommodation in use by the two eyes.
3. Amplitude of accommodation.
4. Lateral and vertical phora at distance and near.

   The lateral phoria is determined in part by the amount of accommodation in play. As already discussed, the accommodation is a part of the triad response and carries with it a certain amount of convergence called accommodative convergence. The ratio of accommodative convergence to accommodation is the ACA ratio. The triad response is subject to voluntary control and usually it is manipulated in the interest of maintaining the best focus. But, if the subject is willing to sacrifice clarity, he can manipulate the triad response to help maintain fusion.
5. The ability to regain fusion once it is broken by putting a prism over one eye.
6. The ability to maintain fusion under the stress produced by gradually changing the power of a prism placed before the eye.
7. Skill in the use of accommodative convergence to help with the maintenance of fusion.

An attempt is now made to compensate for these anomalies by the use of lenses, prisms and training. If this fails to provide comfort, an occluder may be worn over one eye for about two weeks to determine if the problem is monocular or binocular. If it is binocular, further tests are made for cyclophoria and aniseikonia.

The increase in discomfort as the day wears on, and, in particular, the development of headaches and subjective fatigue presents another problem. Sometimes one can find changes in the visual mechanism, but on the whole refractive errors, amplitude of accommodation, pupil size, phorias and fusional capacity as measured in a routine exam remain stable and it is not to be expected that measures of these functions could be used to measure the effect of prolonged use of the eyes or the effect of lowering the level of illumination on visual comfort.

The constant struggle to maintain clear vision and coordinate the two eyes can lead to frustration and weariness. However, because so many other things contribute to these effects, it is difficult to isolate the role of vision.

One can produce temporary changes in the phoria position and the zero level and upper limit of accommodation by making a person use strong lenses and prisms for a few minutes but these effects are temporary and disappear in a few minutes. They are not effects that accumulate over the period of a day and require a night of rest for recovery.

It appears to me that the only hope of getting at the problem is to examine what is going on when a person is struggling to maintain single vision and to coordinate the two eyes.

The pattern of eye movements involved in following objects and in looking now at this and now at that and in looking steadily at a fixed point may explain why a person is not performing as well as he may, but provides little information about the struggle to maintain clear vision and to keep the two eyes pointing at the same point. These are the kinds of ocular adjustments that have to be monitored moment by moment to assess the struggle that leads to discomfort. Such measures might show that lowering the light level is subjecting a given individual to an uncalled for amount of stress.

Only recently have visual scientists had available the instrumentation required for monitoring accommodation and errors in convergence (fixation disparity) and cyclorotation which occur when the eyes are being used in performing a task. The time is ripe for finding out if a knowledge of these microfluctuations reflect the struggle that is going on and the likelihood of discomfort. At the same time we ought to monitor tension in the muscles, tearing, redness of the conjunctiva, blinks and tics, and subjective assessments of comfort.

For a given individual such measurements might reflect when the level of illumination is dangerously low, and explain why a worker is suffering more at the end of a day than at the beginning.

It is possible to speculate about the ultimate cause of the discomfort. The first source to suspect is excessive or fluctuating contraction of the muscles. The convergence component of the triad response involves only partial contraction of the internal recti which is not excessive, and, if pain is involved, it is most likely associated with the ciliary muscle in which, even in a one-eyed man, there is discomfort if an excessive amount of accommodation is called into play. The triad mechanism can be used in helping the eyes to focus and to converge on a point. This depends upon attention to feedback about focus and convergence error and conscious effort in struggling for focus and fusion. This takes its toll in the form of frustration and weariness from sustained attention.

None of this is involved in the fusional reflex which, under ordinary circumstances, maintains fusion without voluntary effort. It has long been suspected that this kind of adjustment of the eyes involves cocontraction of the antagonistic muscles and that the increased tension involves pain in the extraocular muscles. The argument about cocontraction has not been settled. It is undergoing extensive study at the moment.

Cocontraction is probably not involved in accommodative convergence.

Conjugate movements of the eyes involved in fixational movements do not involve cocontraction and are not likely to produce discomfort except at the limits of the field of fixation where the movement is opposed by cheek ligaments and tension can develop. Steady fixation at a point may involve concentration of attention the same as voluntary effort to maintain convergence and focus. These voluntary efforts to focus, converge and fixate involve a symbiotic response of the muscles of the lids and face which undoubtedly contributes to the experience of tension. Wrinkles in the forehead and around the eyes are permanent records of this kind of stress.

It is not very likely that the pain end organs in the iris are involved in the discomfort encountered at low levels of illumination. The only connection would be through the triad response in which fluctuations in accommodation might result in a symbiotic response of the pupil. But the pupil is a good indicator of the discomfort experienced at high levels of illumination. I refer to it because it illustrates how monitoring microfluctuations is a useful approach to the study of discomfort.

It seems to me most unfortunate that a decision has been made to limit lighting to a level at which we have to worry whether some of the people will be able to work in comfort. It would be more satisfactory to justify the levels allowed on the basis that the aim is to provide an adequate level of performance. Workers could be assured that at these levels they can work in comfort if they have normal vision when their eyes are properly corrected with glasses.

DISCUSSION

Dr. Halldane: A very good point here is that the changes in the pupil diameter, by the modeling that we discussed a few years ago, do relate to the changes in the luminance area characteristic of the visual field. So we get luminance area there and this relates to the pupillary illumination on the eye. Now, this is where the application comes in, because that is a thing that could be measured and controlled in terms of a specification. The changes of illumination on the pupil of the eye would be more relevant in application to the engineering and control monitoring of the engineers and so on, including managers, and this could be shown to relate through into the modeling with your discomfort. Now, where the problem comes is in the semantic scaling of what the discomfort is and the specific identification of the responses. Here you have a triad of responses against pupillary responses, etc. You have a whole host of them here; it looks like twenty-odd specific responses. Each one of these responses has a separate correlation model with a physical field. The important thing is that many of these responses depend upon a luminance area, or what I have called a photic field, which is an integration of light area over some fixation period. And, if we understand this, then many of these responses can be grouped under a corresponding physical stimulus measure, notably, back to the pupillary illumination and the changes in pupillary illuminance over a fixation period. With that, all we need, then, is the changes in the pupillary illuminance, related to the responses and the criteria we developed. In other words, how painful is pain and how are we going to describe what we mean by pain and communicate it?

This brings us to the vital problem of reference stimuli, so that each can identify a standard stimulus which we can observe individually and relate to our experiences and develop a semantic scale. This would overcome many of the problems of trying to develop semantic scales into the quantitative data required for the standard.

Mr. Nelson: You do not really mean pain, do you, in the pain threshold concept? You mean discomfort.

Dr. Halldane: This is the problem. Discomfort is an inoperative term.

Mr. Nelson: But pain, to my way of thinking, having worked in burn theory, is that which is intolerable, causing involuntary cessation and removal. I do not think we are talking that level. We are talking—and it is very difficult, because we are talking discomfort. With pain, you cease seeing, you cease looking, you close your eyes, and you turn away. You involuntarily cease what you are doing if you hit the pain threshold, from my understanding of the word pain.

Dr. Halldane: A better example would be in terms of skin responses. In air conditioning, we talk about discomfort; but no one yet, in an experiment as far as I can see, has been able to differentiate whether it is a warmness, coldness, a threshold of sweat on the skin, an itch on the skin, a clinging of perspiration to the hairs of the skin, or what it is as a specific response. Until people identify the response, you can not further the discussion in this field because each has a different correlation model and different stimulus parameters.

Mr. Nelson: Getting back to the effect of lower levels of illumination on people, I read from what you said and what you have added here that there is an area of knowledge, that there is a problem, and lack of good data on developing the relevance of the problem. What I am asking is, in our understanding of the problem, have we reached the point where there is clearly an area in which this problem does not occur, and there is clearly an area in terms of the physical conditions that a man faces in which the problem is almost certain to occur, and, then, a gray area in between? Am I right in an assumption that says that with steady light and steady conditions in steady job this strain would not occur? Either you can read or you can not read, but it does not come to strain?

Dr. Fry: You have asked, I think, a very good question. As a matter of fact, at the present time, illuminating engineers do not concern themselves with this problem of eyestrain. They consider themselves to be working above that level. In your terminology, we are thinking in terms of upper levels. And we try to differentiate between good and bad lighting in terms of the increased performance of the worker. Thirty years ago, we were concerned with these low levels of illumination at which this type of thing would occur. Now, the problem is that it differs from one individual to another. For example, an individual who begins wearing contact lenses is more sensitive to pain from contraction of the pupil because this is added to the pain from the cornea. I am very careful to differentiate between pain and stimulation of pain fibers. I do not know any other way to explain it. It is what I would call a subthreshold stimulation of pain fibers, subthreshold for pain. That is the concept that I have been entertaining, at any rate, insofar as discomfort is concerned and also these reflex mechanisms that constitute the sequelae of eyestrain.

Now, the contact lens illustrates one thing. If you have an individual suffering from an eye defect—that is, astigmatism or a difference in focus for the two eyes—working under low levels of illumination, he will develop symptoms of eyestrain; whereas, the individual who is free from refractive error would not have any problem at all.

Mr. Nelson: But is it possible to establish anything like the parameters that you stated. When we worked on an accuracy basis, we were so clearly out of this range that it was not something of concern; whereas, years ago—and when we were talking this morning—we did have this. And have we got anything as a starting point while further research and development goes on that says this set of illumination levels with these sort of contrasts, or what have you, are clearly out of the range of causing this type of eyestrain? Can this be established from the existing literature?

Dr. Blackwell: I have some data which I will present shortly.

Mr. Caplan: Well, I think it had to do with your comment about pain. We are struggling with that in NIOSH as far as what is discomfort, what is toxicity, what is disease. And it is really a very difficult thing. You can not use the criteria that a person will withdraw from that situation, obviously. If you have a headache, there is no way of withdrawing. If you have an irritant in your jaw, for example, you can not withdraw from that. You suffer, and you can call it discomfort if you want to; but, on the other hand, it is something that is undesirable and it causes physiological changes that are unpleasant.

Mr. Nelson: I think we are talking something different and I will have to use my example. As I stated before, the majority of my work has been in fire safety. And I can draw you charts in population distribution—the Air Force did it, in fact I think the Germans did it with some of their rather horrible experiments—but, when a certain point in radiant energy exposure occurs in an exit way, it is humanly impossible to pass that radiant level and exit through that opening. Even if you could survive, your body will not permit it. Pain alone controls the ability to act. That is what I meant when I said "pain."

Mr. Caplan: I do not see how you can call that not pain when it is lower than that value.

Mr. Nelson: Well, alright, but this is part of the vocabulary problem that we have; and I agree with Dr. Fry that these are subpain threshold stimulation of pain nerves. Either you are going to use my terminology, or we throw it out and use yours; but we ought to have one between us. Something like "discomfort index," though that is not a good word, because the air conditioning engineers are already using it for a different meaning.

Dr. Halldane: An impeding of a response, this is the key thing.

Mr. Caplan: Irritation, for example, is a response, a physiological response, which is in the definition that we use, a toxicological response. And it is unacceptable and it is toxicological. It is bearable—I mean a person will continue to work there; a person will continue to work in a heat environment of a hundred degrees, Effective Temperature, not very long but he will do it. He would want to get out, but he would continue under certain circumstances. So what is bearable and what is unbearable is a positive term. There are a lot of other factors that are involved.

VISUAL DYSFUNCTION

H. R. Blackwell, Ph.D.

Dr. Blackwell: Mrs. Blackwell and I have an integrated performance here. I am going to talk first for, I hope, about fifteen minutes—I hope I can get it in that time. She will talk then for about twenty and I have five more at the end to bring up another topic.

In order to get on with this and save time, I will hold until tomorrow discussions about other than those we measured when observers are correctly optically refracted and are tested at the distance for which their refraction is known. In other words, there are special effects of lighting variables, such as luminance, in changing the pupil size, which change the depth of focus of the eye, which make a great deal of difference to the comfort of a presbyope such as I—many of you, I am sure, know what I am talking about. I am not going to be concerned with those today because our time is short. Tomorrow we will talk about those.

Now, basically, my wife and I have been working for a great many years on what is called visual performance. We realize this is not what you want to hear about today; and so I hope you will see that we made an effort to tell you what you do want to hear about, which is to tell you everything that we think we know about the likelihood that there is, in any sense, a health problem in reducing illumination levels. As a former worker in the Institute of Industrial Health in Michigan and a publisher of papers in that field, I do, I think, understand your problem. My own view is that it is not proper to regard as a health problem a loss of performance; and probably not as a primary health problem the knowledge on the part of an observer that his performance is reduced. The person who says, "I can't see, doc," does not, necessarily, in my opinion, have a health problem. He just can not see. His performance can be shown to be bad.

In short, I am going along with the lay interpretation that health gets involved when people have symptoms; and symptoms, at the very least, involve complaints, which are: "This lighting is ruining my eyes," or "I have headaches," or "My eyes hurt," or something of that sort. Now, I am quite convinced personally that all these symptoms have to come about, not through the sensory systems—you know, the retina has two million photodetectors, subtle design, solid state — these can not hurt. There is no way they can. A subject might infer that there is something wrong if he can not see, but I am not concerned with that. I think symptoms are involving the ocular motor system, which Dr. Fry so beautifully described for you.

Now, I am sure you have, from his presentation, the idea that these ocular motor systems are very delicately adjusted servoloops which involve sensory input. If you can not see anything, the systems can not work. If you do not believe it, go into a uniform field or total darkness and measure what these crazy things are doing. In the case of uniform field, they search for some fix. The servoloop, in short, is open.

Now, what I want to do, is talk to you a little bit about what it is we do with light anyway. We heard about everything else but, today. And, most particularly, then, I want to say what I think we can say about the effects of reducing light levels in order to save our National power. The way I want to go about this is to talk about what I call suprathreshold visibility. You will see why, I think, in a moment. I want to use as my index the way the system works, how well the system can operate, how far it is above the level of no function at all. I think I will make that clear as I go along.

I might say something about thresholds. A threshold is an arbitrary concept. It is easy to measure, and it turns out, in our opinion, to have very predictive power in explaining a great many things about the way light affects vision. This is a curve now standardized by the International Commission of Illumination. My wife and I obtained the data. It does not matter too much about it except for the curve form. This is a double logarithmic scale, so there is a meaning to talking about the curve being flat or steep. What does this curve say? It says that, if you take normal twenty to thirty-year-old observers, each of whom has been individually refracted and is known to be in perfect focus under the experimental conditions, that, if you increase the luminance level — and thanks to Dr. Halldane for making it clear, illumination means nothing to the eye, it is luminance that does—this is luminance, of course—that what light does, as a first order of proximation, all that it does, the primary thing that it does to the visual system is that it increases its contrast sensitivity. It increases its sign wave response. This is a control system. This shows that, indeed, as you increase luminance—to be sure, this is over eight logarithmic units—from the darkest night to the brightest day, you get a change in the extent to which the eye can detect the difference in signal—that is, the difference between bright and not so bright, or bright and a little bit brighter—which itself changes more than three and a half log units.

It is not a linear change, as you can tell. At low luminance levels, changing the luminance by one log unit, moving over a certain distance, changes the sensitivity an equal amount. When the curve drops, the sensitivity is increasing. This curve is conventionally plotted showing it falls, meaning less contrast is enough for the eye to work. You can see that, on the other hand, by the time you get into high light levels, there is essentially nothing that happens at all. The curve is, essentially, absolutely flat. Now, lighting levels, of course, to tie this all in, in footlamberts, can be seen by these logarithmic scales (10^1, for example, means ten footlamberts; 10^2 means one hundred footlamberts) and let us say that all lighting standards are within the range of those two numbers. So we are only talking about, with the exception, of course, of roadway lighting, interior lighting which falls within ten and a hundred footlamberts in anybody's specifications. So you begin to realize what a rather narrow range a change of two to one is. A change of two to one is three-tenths of a log unit, which on that paper, on that graph, as you can see, is a third of the way from ten to the first to ten to the second. There is definitely a change in the curve saying that, when you change the light level — the luminance, that is — by a factor of two to one, cutting it down by two to one, you definitely do something to the eye. You change its ability to pick up differences in luminance which, we maintain, is the fundamental aspect of all visual functions. I do not have time to justify that; I will be happy to do it tomorrow. Today, all systems are explained in terms of sign wave response. We have been doing that for the eye for thirty years. It turned out that we made a very good choice. Contrast is the proper thing to use to describe a system.

Now, in these experiments, the pupil was allowed to vary in its natural way. Experiments in which the pupil is fixed are good physiological experiments but of no use to lighting. In these cases, the eye was changing its pupil size as the experiments were done and so, whatever that did, making things better or worse, was included in the experiments. As you will see, we had older observers and, undoubtedly, we know that Dr. Weale is right that, in these cases, the pupils were not changing the same as in our normal observers. That is part of the reason why our data look as they do. Now, what is the point? If you were to try to provide threshold seeing and no more, there would be no need for a conference here at all. Let me say, we would be talking as Mr. Crouch indicated, about extremely low light levels for most objects, and because most things are easy to see when you know where to look, look right at them, and have all the time in the world to look. This is what makes the lighting problem so difficult to understand. Is it true that you cannot see this handwriting? Of course it is not true. Could you look right at it? I can read it. I could read it if you turned the lights off. It would take me longer, but I could read it. In other words, threshold performance is very low performance indeed and would require extremely low levels of light, and there would be no need for a conference.

The problem arises in that vision is probabilistic. That is, the curve I have shown you before represents one point on a probabilistic curve. It represents, in fact, the point at which the accuracy of performance was fifty percent. Scientists picked that point only because the curve is steep at that value and high precision can be obtained in measuring the results. That means that half the time, on the graph I showed you before, those objects were presented, half the time people would fail to see them at all. So our threshold is a completely unworkable thing and no one would want to prescribe lighting at that level because it means half the time you would see absolutely nothing and half the time you would see something.

Dr. Riegel: When you say "half the time," the exposure time was a fifth of a second?

Dr. Blackwell: In those experiments, the exposure time was a fifth of a second. I did not say that, but it said it on the slide. Pardon?

Dr. Halldane: That is binocular vision?

Dr. Blackwell: Binocular vision, right. As a matter of fact, if you extended it to five seconds, it would make remarkably little difference. What you do when you give longer exposures than a fifth of a second is allow the eye to look again. The eye gives itself fifth of a second exposures because it stops and looks for that length of time. So it would not make a lot of difference if I had shown you five-second data. We have them and have published them, too. But the main thing to say is that "threshold" really means only half the time do you see anything at all. And, if I were to show you threshold lighting conditions, you would agree that this is an intolerable way to have to work, because you can not see anything at all half the time.

Now, the point is that it only takes a factor of two in contrast to find — and I will not justify it today because of time — that contrast turns out to be a most useful metric. It turns out that the system does have contrast sensitivity as its primary response measure. But, never mind that. Even if that were not true, we found a way to put it altogether in terms of a contrast scale; and let me do that in the interest of time. The meaning here is not that I need a level of light twice as high to go from fifty percent to a higher percentage, let us say ninety-nine percent, I need twice as much contrast. The language we use is to say, let us talk about the real world in which things are more visible than threshold, in terms of a linear physical metric, which is simply how far above threshold contrast they are. Now, this curve tells us that, if I have a suprathreshold factor of two, the meaning is that now you would see it every time I presented it, 99.99%. But, in a sense, if I reduced it at all, some of the time you would not see it. And, interestingly enough, if I asked you how sure you were you saw it, even though you saw it most of the time, sometimes you would say, "Well, I'm not sure, I think I saw it," sometimes you would say, "I'm quite positive I saw it." So confidence is another matter, too. Let me say again that, if you were satisfied to provide lighting only to the point of ninety-nine percent accuracy, under these conditions, where the eye is looking precisely in the right direction and knows exactly when to expect something to happen, you would need essentially no light. You could get by with almost none. This confirms again what you have no doubt experienced. You can take a newspaper outside. If you want to see one thing and have plenty of time, you can see it; you can see it all the time, as if I presented it time and again. So, in a sense, moonlight levels are sufficient if you are willing to work at even a suprathreshold factor of two.

Now, let me just sort of give you a feeling for where things stand. The fact is the American IES standards represent a degree of suprathreshold seeing that corresponds to eight, eight times threshold. It does not matter that in 1958 when I did my first work and they adopted it for a standard they did not know that. They know it today and that is really all that matters. So, in terms of our new international scale of suprathreshold visibility, present lighting factors correspond to a suprathreshold factor of eight. That means that contrast would have to be cut to one-eighth by some means, such as an instrument, before one would get to the point where one sees only half the time. This is, in a sense, a safety factor, a field factor, call it what you like. We like to call it a suprathreshold. If you cut light levels by one-half, if you started with a hundred footcandles as a starting point and went to fifty, you would cut the suprathreshold factor from 8 to 7.29. So now you have some kind of an idea of where we are operating with current light levels and where we will be operating—or are operating in cases where it has happened—at light levels reduced by a factor of two, from visibility level (VL) 8, or suprathreshold factor, to 7.29.

Now, what I want to do is give you some idea of what the suprathreshold world is like so you can begin to see what you need to know to determine whether or not going from a suprathreshold factor of 8, which is current American practice, to your half values, which is 7.29, which is a serious change in light levels. And, after I give my first presentation and my wife gives her presentation on age and individual differences, then I will come back and tell you all we know today about where the public health aspect might come in. That is, I am going to try to tell you at what value of suprathreshold factor discomfort and symptoms are likely to occur, based upon some measurements we just finished making.

To go back to be sure that I made my point clear, if I have an object which has a certain physical contrast — let us suppose it is a piece of black print, and suppose it happens to be a four-minute spot — I know that the physical contrast of that is one by definition. (Blackwell, 1946). This means, then, that I can put a dot on my graph corresponding to the physical contrast of one. Let us say it is also possible to describe other objects in terms of the contrast of a four-minute disc having equal visibility. And so I can put real objects on this graph in a physical sense and say here is how visible handwriting samples of this kind are, here is how visible bold, black type is, and so forth. The point, of course, is what is done by changing the luminance level. One changes the contrast sensitivity a little bit; and, if the object is a fixed contrast as it is when it is kept in the same geometry, one simply dims it. All we do, then, is change how far above threshold it is. And that is why I made the statement that going from one hundred footcandles to fifty footcandles has changed the suprathreshold factor only from 8 to 7.29. And so the world that we live in is a world all above this, above it by quite a sizable amount. And the question is, do we have to have things that easy to see? What happens if we do not?

I have shown you the probabilistic nature. I am saying that it only takes up to a suprathreshold factor of two to get out of that range where sometimes you do not see at all. And so now we are concerned about what happens from two up. What do you get, in short, by having more visibility than a suprathreshold factor of two? Well, some years ago, my wife gave these results at Munich, 1962, International Congress of Optics, showing one of the things you get for your money if you increase the suprathreshold factor above one. These experiments were done with a letter "E". The letter "E" happened to be brighter than the background, so we could achieve high values of contrast to be sure we had gotten the last ounce of visual performance out. Visual acuity is plotted over here on a logarithmic scale, and $c/\overline{c}$ is the physical contrast of a letter divided by the threshold contrast for just seeing that as a blob of light. So this is the detection threshold, $\overline{c}$. These numbers down here, then, are suprathreshold factors, directly. And so we see one, we see three, we see ten, and so on. This particular set of data were obtained at 2,460 footlamberts. They tell us that, if we were to provide, by lighting, a suprathreshold factor of ten, we would get a very, very high acuity, better than 20/20, in fact. This is the 20/20 line, right there. If we cut the level down, we would cut the acuity to some point. If we increased it, furthermore, we would get almost no improvement at all. In other words, we immediately see that, not only is it not true that a doubling of light doubles visual sensitivity in terms of suprathreshold factor and its consequences—it changes it only a small amount—but also, we see that the consequences of a change in suprathreshold factor are also nonlinear. We see that, indeed, once you get to a suprathreshold factor of ten, it makes very little difference whether you have more. This suits common sense because you sort of know intuitively that it can not be true that making something more and more visible like a roadway sign, if you are looking right at it, that it is absurd to think that there is any advantage in making it more visible than it is. The darned thing can not be missed; it is extremely visible.

This is a general result. In each case, understand, there is a different value of $\overline{c}$ because the eye sensitivity is affected by luminance. But the point here is that the suprathreshold nature of the acuity return is the same at different luminance levels. This one goes out further. There is a very small drop at the far end, representing the fact that the letter is now so contrasting, so visible, that there is a little irradiation involved and it gets harder to see. This does not occur until you get up to a suprathreshold factor of about three hundred.

DISCUSSION

Dr. Yonemura: I am a little bothered. I think visual acuity, by definition, is the threshold. You see a gap, an opening . . .

Dr. Blackwell: I am sorry, I explained that what we did was to look at it in terms of the CIE system. And we measured, in this particular case, and we talk about the detection of the letter, as a blob, as a base line.

Dr. Yonemura: That is detection threshold. Now, I am talking about acuity threshold.

Dr. Blackwell: And we are showing, of course, that when you go above a threshold of one, acuity begins to improve. In fact, at detection threshold, acuity is almost nothing at all.

Dr. Yonemura: What is the definition of acuity?

Dr. Blackwell: Well, of course, they can tell us it is the letter "E". They are setting this to a recognition criterion.

Dr. Halldane: It is not the separation, Dr. Yonemura, it is the detection threshold.

Dr. Blackwell: Absolutely true. This is the point that I am trying to make. This relates directly to Dr. Yonemura's work. Let me, if I may, take one minute. Do not count it against me because he brought this up. Let me say the following things. Dr. Yonemura has started to work in a very interesting area, which I think will come out tomorrow. He started to work in the area of what happens to vision far above threshold. That is why he is asking the question the way he is. Let us put it another way. What happens if I look at something and it is so contrasty that there is no threshold problem, making it easier to see than that, what does it do for us? Is there a kind of constriction? We will talk about that tomorrow. In fact, this shows that there is. What I am saying is that you do not continue to get any performance improvement for this recognition problem once you get up to a suprathreshold factor of about ten. Do you follow me? I am saying that this definition is arbitrary. I could have another one; but this illustrates an important point which is that making something easier to see buys you an ability to do visual resolution up to a point and then it buys you nothing more at all. And the point comes at ten. I could really express these as a threshold of acuity; but I choose to do it this way for, as I think you will see, a good reason.

Dr. Halldane: Could I ask one question, and that is, was the visual task of the observers to detect clearly the E form and separation of E letters, or was it purely to detect a blob?

Dr. Blackwell: Well, I sort of think I have explained that. Let me say it again.

Mr. Crouch: I do not think you explained it. I have not followed it.

Dr. Blackwell: Two things were done. First, the observers were asked to detect this thing as a blob, to tell whether it was there or not.

Dr. Halldane: That is not acuity.

Dr. Blackwell: Of course not. And that is used to define $\overline{c}$, which is simply the base line for what we then do. Then, the question is, as the observer increased the contrast by turning a control, to use the eye doctor's phrase, "Dearie, you can see the letter and know that it's an E?" The point is that, if you start with detection threshold, acuity is extremely bad. By definition, you can not tell that it is an E; it is a blob. And so, sure enough, the curve comes down almost like a shot. That really is not of any interest. The interest is what happens as you begin the increase the contrast above that. This shows you that you have to come up a factor of three in contrast before the person has any idea at all that it is an E, even when it is extremely large. And then, as you go up further and further, the person can begin to see a smaller and smaller letter E and know that it is a letter E.

Now, the experiment is complicated experimentally because you have to keep measuring the $\overline{c}$ as you change the size of the E. My wife did these experiments, and so it is an interrelated experiment. In other words, you have to end up with a number which says the acuity was 20/20 here when the letter was five times the contrast at which that same letter could be seen as a blob. Again, the point is, this is a kind of exploration of the suprathreshold domain; but, in a sense, it really is not. It is still threshold in another sense. But the point we wanted to make is that, when you express the data this way, all these curves have the same form and they illustrate a most important point, which is that—I do not have a slide, but you can tell by looking—all those things are going off at the same value, the same acuity. If you superimpose those graphs, they all fall together at the top.

Now, to make Dr. Yonemura's point, what this means is that, once you get to a suprathreshold factor of around a hundred, there is absolutely nothing, no benefit of any kind in terms of spacial resolving power to be gained by going further. Now, I am not sure you wanted to go further, but one needs to know at what point there is absolutely no return. There is some return at thirty, but a lot less than there is at ten. And this illustrates a most important point, which is, as you go up into the suprathreshold domain, things are not linear at all. And, the closer you are to threshold, in a sense, for this experiment where the observer knew right where to look and to look at the letter E, the benefit of going higher obviously stops at some point. There is essentially no reason to ever talk about going beyond about thirty. Is that clear now? That is the experiment.

Dr. Weale: There is one point which worries me a little, and that is the reentrant shape of the curve. In other words, for one value of $c/\overline{c}$, there is a good and a bad value of visual acuity.

Dr. Blackwell: Right. The explanation is quite interesting. We do the experiment by taking the size and moving it across this way. And so we can do it this way and this way and those two experiments are not confused to us because we know what size we are working at. The reason this thing bends back is, of course, neural inhibition or, possibly, the interjection of rods. These are rather large targets. If you cut them off at the visual acuity, you see, point one visual acuity is twenty-two hundredths which is ten minutes for the detail, which is fifty minutes for the letter. So this is getting rather large, but we are trying to get down here. You are beginning to possibly involve rods. So I might have been wiser to have erased the bottom part of the curve. But this is what we got, so I presented the data.

Dr. Weale: Well; I do not want to press this, but you could have done the experiment another way which I think ought to provide you with a means of checking your explanation. Supposing you had set up not one target but two, side by side. Then, it should have been possible, in theory, to present one to provide your $\overline{c}$ and the other c and you should have found an identical probability of seeing curves for a low and a high visual acuity respectively in that rather restricted $c/\overline{c}$ range.

Dr. Blackwell: What we did, in fact, was to do the experiment both ways. We went up this way and hit the curve. When we got into this part of it, it was much more efficient to go this way. And so we, in fact, did both.

Dr. Weale: But you did not, if I may say so, do it under two different conditions. In other words, did you not change your criteria when you did this?

Dr. Blackwell: No, we did not. We did it on the same curve. I did not bring that slide along. This is a rather minor point. I would rather push along, because, as a matter of fact, if you do not even like this, it is not terribly important to the main thing I wanted to say. I wanted to show you everything we know today about the suprathreshold domain. And I can not talk about visual performance, because that is out; and that is the main thing I have worked on.

Dr. Halldane: I want to tell you that your data is not inconsistent with the concept that Dr. Yonemura—

Dr. Blackwell: I know that. Indeed, I would say that this a beautiful repeat of the experiment he did using the Bryndahl paradigm and I hope to bring that out tomorrow.

Dr. Halldane: The point I am making is that you asked the person essentially, in the first part of the experiment, for his blob. The detection threshold is a visibility threshold, extinction threshold determination.

Dr. Blackwell: Right.

Dr. Halldane: The next one, he does not specify what the judgment is. The person has the option of judging it by visibility or a combination of clarity, which is what the others and I were interested in. Clarity depends on the blur of the contour in the visual field. Blur can develop through lateral inhibition, in terms of physiological mechanisms, and entoptic scatter, which is very important throughout design ranges.

Dr. Blackwell: Of course.

Dr. Halldane: These are the two principal ones. You can get either the blur of the darker edge of the contour, which explains that folding back of the curve or the higher contrast; you get the entoptic scatter bleeding over on the darker side.

Dr. Blackwell: Let me show you why I presented these data. I thought Dr. Yonemura would have given his talk before mine. It is rather unfair, in a sense, that he did not. I wanted to show what it is that suprathreshold visibility buys you. I am saying that, in terms of ability to pick up resolution targets, which may, indeed, be the same thing as a clarity index, it does buy you something up to a level of about thirty. Furthermore, if I took these very data — I have done it, but I do not have a slide—I can get an identical contour with the one he gets by measuring apparent contrast enhancement as a function of luminance. If I have luminance down here, I can show that acuity goes up when the suprathreshold factor is not too large. But as it gets larger, it begins to become nothing at all. If I go out to the end of these curves where they are flat, they tell me that luminance has no effect at all on spacial resolution even though the suprathresholdness is changing because the contrast sensitivity of the eye is changing. And so I am saying that here is a direct confirmation—in my opinion, it is another way of doing the same thing as the Bryndahl experiments—showing that there is a kind of compression of dynamic range that occurs at high luminance levels; but that it is not so bad that it ever results in a loss in performance. It either has a larger or smaller beneficial effect. Now, I better get on, because that is a minor point and, as I say, I thought Dr. Yonemura would have talked already.

Let me say once more that this is a case where the eye looks right at a letter and has no searching to do. The object is made extremely visible and clarity ceases to improve, if you want to say that, at a value above the threshold for detection as a reference point of something like about thirty. The effect is small before you get that far; it begins to taper off. So we know, now, there are two nonlinear transforms involved between a light level change of two to one and this is the kind of capacity that the eye develops.

Now, the other way you use up suprathreshold visibility, so that you can justify even talking about something more than two, is that, most of the time, we maintain the eye is not in a position to look directly at a single object, knowing where it is going to occur and simply, in effect, drinking it in. Indeed, the nature of the visual process is the eye constantly moving, searching, and scanning, in a world with a myriad of detail. And so, what I am saying is that even though, again, we have used a threshold measurement technique, we have used up the suprathreshold range by making the viewing conditions more difficult. If you require that the eye search and scan in a dynamic experiment—this is the one that Mr. Crouch showed the slide of a girl and a wheel, that was our experiment and these are data obtained in it, published in 1970 by Blackwell and Smith—the point is the same, observers measured their static threshold when they were looking right at an object for a certain length of time, in this case, the time was 2.4 seconds. Then we gave them a dynamic task in which they had to search and scan as the wheel went past; and the number of times the wheel went by was matched. So, in effect, they had 2.4 seconds per object available for looking; but, in the second case, they had to search and scan.

Now, what is the point? The point is that the threshold curves in the two cases are similar in shape but displaced. So that, in this particular case where it was not a very demanding search task, it took 1.37 times as much contrast to do the dynamic task at a fifty percent accuracy level as it did to do the static one. The point, of course, is that in normal life, if we give you more than a suprathreshold factor of two, you use it up in being able to do dynamic tasks.

The next one shows a more demanding task. The solid curve is a one-second exposure of an object when you know where to look; the dashed curve is one second per object in a dynamic task. And the multiplier on the contrast scale is now 1.56; the curve is really remarkably parallel.

Dr. Halldane: Is it elevated, say, from an eight factor, or is it times the eight factor?

Dr. Blackwell: Nothing is being said about that at all. I am talking about using up—this is not the eight factor at all. Eight factor happens to be where the IES works. Never mind that they use these to develop a rationale for the eight, I am talking about . . .

Dr. Halldane: Say you were performing at a six factor as a static condition, at a dynamic situation, what factor would you increase by?

Dr. Blackwell: You can not do that. You cannot operate a threshold at a six factor. By definition, you are operating at a factor of one.

Dr. Halldane: This is not threshold we are talking about, this is supra.

Dr. Blackwell: The solid curve is, in each case, threshold in the classical sense, fifty percent accuracy when you know where to look. So each of these is a new base line curve on different observers under different conditions. The point is that if I give you a suprathreshold factor of 1.9, you have the same accuracy under conditions involving more search.

Here is another one. Here, now, we have gone down to an exposure of two-tenths of a second. This is the one the IES used of this family of curves; but never mind how or why. It is not the point I am trying to make. This shows that, when you have five items coming by per second—now this wheel is moving pretty fast—it takes a 2.78 factor to achieve the same accuracy that you had at threshold; namely, fifty percent. And finally, when you had a one-tenth-second exposure—either fixed, in the bottom case, or you had ten items a second going by in the top case, the machine practically beats itself apart—it takes a factor of five.

Now, what is the point? I am saying that in real life the reason that you have to have suprathreshold factors at all is that you are never looking in quite the right direction. And what you do by providing a suprathreshold factor, as I suggested in my 1958 paper, is to give the eye the ability to see things further away from where the eye is pointed. You see, the visual system has a very highly peaked sensitivity response. If you do not believe it, find a star outside in the daytime and look away from it and try to find it again. You can look and look and look and not find it. That is why the Asians went down in a well to look at a star in the daytime.

Dr. Weale: This is said to be a fantasy.

Dr. Blackwell: Not at all, I have done the experiment in a laboratory, without the well to be sure. It is not a fantasy at all. If you give a person this much information about where to look, of course he can find it more rapidly. The fact is, look away from the star in the daytime and try to find it again. You have to get lined up exactly with it again in order to see it. We measured the contour. As you go out minutes of arc, beyond five minutes of arc, the threshold rises. And, by the time you are forty-five minutes away, it is to the order of a factor of fifty percent.

Dr. Weale: I was on your side, but Fergus Campbell apparently did crucial experiments and he is against you and me.

Dr. Blackwell: Well, I am sorry, but I remain convinced that this is the way the system works. It does not matter, in a sense. These are empirical results obtained in an empirical experiment. My interpretation, you can take or leave. I know for a fact, from my records, that these people cannot keep up with the speed of the object and are, indeed, being forced to look at things off the line of sight; and I know for a fact, because I have done the experiment, when things are off the line of sight, you see them less well. You can repeat the experiment for yourself anytime.

Dr. Halldane: You have phototropic distractions when you have that dynamic situation.

Dr. Blackwell: Right. Now, the point I am trying to make is that everything I have ever done, in a sense, is threshold. But I have shown—let me finish, and tomorrow you can talk about suprathreshold all you want—my suprathreshold is different from yours and I wanted to make that point very clear because I have used up my threshold in one of two ways, my suprathresholdness. Either I have shown that the eye develops better resolution capacities—that is the first set of data on the "E"—or I have shown the eye can operate under conditions involving more search and scanning, if I give the eyes suprathreshold vision. And, since this is what light does, it seems to me rather important that we know what we are doing when we go from a suprathreshold factor of 7.29 to one of eight. Now, we make some progress, quickly, I hope.

We have a device called a visibility meter. The only purpose of it is to equate at threshold, since this is the point of greatest precision of the psychophysical judgments, any real object with an arbitrary reference task, which happens to be a four-minute disc exposed for a fifth of a second. The principle is that you cut down focused light from the object and add veiled light equal in amount so that adaptation of the eyes stays constant; the object looks like it disappeared in a fog, except that the fog keeps the same luminance as the object disappears. Here is the optical design of the instrument we are using. It is not the one Mr. Crouch showed, he has an old model. That is a Model 2 which is out of date. Here is a Model 3. It has a nice black box. It has as many optical parts in it as my Chrysler has mechanical parts under the hood, just solid, jam-packed, not an eighth of an inch extra space. What do you do? You look at an object; you turn a knob as this flashing goes on until an object is barely visible. You can do this at any criterion you want. You can do it as a resolution criterion, a detection criterion, any kind of information criterion.

Later you calibrate yourself on a four-minute disc, because you simply want to say this object is as visible as a four-minute disc with a measurable physical contrast. The idea is that this cancels out the operator of the visibility machine.

Once you have done that, you can then begin to talk about the suprathresholdness of any object which anyone has ever studied in the history of visual performance. You can ask yourself: What did Weston do when he took his rings that were mentioned this morning and had different sizes and different contrasts and different illumination levels? I, today, can sit down with rings made just like his, by his prescription, measure them in the visibility meter, and, using that first curve that I showed you, compute what we now call the visibility level. The visibility level is exactly the same thing as the suprathreshold factor except that the reference is not one individual but a population of normal observers. In a general sense, you take each individual and measure his own suprathreshold factor on him. When you do not have the observers, you refer back to a reference standard population.

The point I am making is just to show you, quickly, some performance data to illustrate that we have managed to find something that does describe what it is that lighting does for vision, at least as far as these dynamic, real experiments are concerned. These are Mr. Weston's own data, analyzed thirty-five years after he obtained them. These data put on one curve all the experiments he ever did in which he changed the ease of seeing the Landolt rings by changing their size, by changing their contrast and, of most practical interest, by changing the amount of illumination. When you use this visibility level system of measuring, all these data fall on a single curve. The fact that they fall so regularly on a curve has convinced my international committee of experts that the visibility level really is a fundamental description of the ease of seeing a particular task, taking into account the amount of light, the size and contrast and so on.

Now, what is the point of the slides? Merely to show you something else you buy when you have visibility level or suprathreshold factor. You buy better performance in realistic tasks. This shows that in Weston's experiment, when he measured the speed and accuracy of cancelling these Landolt rings, as the visibility level went up, performance went up. And so you could, if you wished, say, well, what happens with a VL of eight? Draw a line up and see how much performance you have. How much do you lose if you cut the lighting level in half and go down to a 7.29? You can figure out how much it is. But that is visual performance. But I wanted you to see, by these three examples, Dr. Bodmann's experiment with numerals. It is actually one in which one spends twenty seconds finding the right numeral so that the curve is quite flat as it turns out.

Boynton and Boss used an ocular search task. In all these cases, the people who did the experiments and I were amazed and gratified to discover that, when we did this visibility meter measure and computed the changes due to illumination, illuminance, the data all fell on a smooth curve. Let us say that I have in my briefcase, but not in the projector, additional ones of this sort done by Dr. Smith. Dr. Smith did the needle task; I have a slide showing that visibility level is the thing that determines how well you can perform a visual task and could, of course, be a criterion—as the IES has used in the past—for deciding how much light you need. But never mind about that. That, indeed, is Dr. Smith's task and that is another one. I forgot I had the slide in the projector. In all these cases, visibility level explained what happened. Now, in none of these cases would you call these threshold experiments. These were realistic visual work situations in which one either used speed or accuracy or a combination of the two as a measure. Let me say that I think I know why these curves come out as they do. The shape of them reflects the extent to which the task involves off-axis seeing. We are currently pinning that point down. So what I have tried to show you, then, is that visibility level is something you care about. Remember, suprathreshold level is when you take it one by one, one person at a time. Visibility level is when you cannot do that because the people are not around. You make a visibility meter reading to get the difficulty of the task and reference it to the threshold of the observers I showed at the beginning. And I have shown you there are three things you buy when you had additional visibility level or suprathreshold factor. If a task is fixed in position, you get spacial resolution up to a point, about thirty; but it is not linear at all. If the conditions of viewing require search and scanning, you can scan more and more difficult tasks as you have more and more suprathreshold factor. And, finally, realistically speaking, more suprathreshold factor always gives you better performance in visual work conditions.

Now, the question is, forget about all that, what can we tell you about the change you have made or wish to make nationally standardized in cutting light levels in half? Can we give you any insight in what you are doing to the population of this country in terms of the visibility level that task will have for the different people in the population. My wife will give you the results. I introduced this because you have to understand what visibility level is and what it means. And she is going to tell you — and we will give you throwaways to show you the graphs—what happens, then, if the whole population of the United States is changed over from a system giving them VL 8 to one giving them 7.29 on the average. You will find that some people have visibility levels of less than two and some people have visibility levels of more than twenty. That is the population effect we most want to bring to your attention. And then, I want to come back for about five minutes and talk about the ocular motor system and show you that the ability of the eye to fixate, the ability of the eye to make movements from one point in space to the other, is, again, directly related to visibility levels, suprathreshold factor, which is, itself, related to light levels only by means of a nonlinear transform, the one I showed you in the first place.

INDIVIDUAL DIFFERENCES IN CONTRAST SENSITIVITY

O. M. Blackwell

Mrs. Blackwell: The data I wish to present to you today were obtained in a study of contrast sensitivity as a function of luminance for 156 observers of ages varying from 20 to 70. These data were reported in *JIES*, Vol. 1, No. 1, Oct. 1971, in an article by O.M. and H.R. Blackwell. The details can be found there. We obtained contrast sensitivity curves on 156 observers for uniform background luminances from 0.001 to 500 fL. (or .003 to 1710 cd/m^2) for a 4-minute disc, presented in a continuous train of 1/5-sec. exposures in the center of four fixation lights adjustable in luminance. Each observer was required to adjust the luminance of the 4-minute disc until he could just barely tell that something was there—a detection threshold.

It should be emphasized that we selected our observers to be so-called "normal." This is here defined as meaning that they were free of any ocular defects discernible under the usual clinical examination and that they had a visual acuity corrected or uncorrected of at least 20/30. We selected our observers in this way with the idea of adding in the effects of abnormalities in proportion to medical statistics of their occurrence in a relevant population at such time as our studies have elucidated their effects. We found that this method of selection made it more and more difficult to find observers as age increased. This is another way of saying that our older age groups do not represent the "average" of their age group but more likely the optimum of their age group. We arbitrarily divided our observers into 10-year age spans including all the observers we had studied up to a particular time. For this reason, the number (N) for the different groups is not the same. This should be kept in mind in evaluating the data.

With this as preamble then, I will show you the data and show their use when applied to the lighting standards problem. Figure 1 shows the contrast sensitivity for 68 "normal" 20–30 year old observers for uniform background luminances of 0.001 to 500 fL. (.003 to 1710 cd/m^2) for a 4-minute disc presented in 1/5-sec. exposures. This curve has been adopted as the standard visibility reference function in CIE Report No. 19. It serves as an arbitrary reference base to which to compare the contrast sensitivity curves of the succeeding age groups. Figure 2 shows the contrast sensitivity function of luminance for 22 observers of age 30–40. The ×'s are the actual data points. The solid curve shows the data for the 20–30 year old reference population. The dotted curve is this same visibility reference function translated upward on the contrast scale to make the best fit for background luminances above 0.29 fL. or 1.0 cd/m^2; that is, those luminances considered important in the specification of interior illumination.

In so far as the data can be fitted by the reference curve translated upward on the contrast axis, to that extent can the effect of increasing age be described by a simple multiplicative factor applied to the reference data from the 20–30 year-olds. In Figure 2 we see that the data for the 30–40 year-olds are well fit by simply multiplying the reference data by a factor of 1.17, meaning that the average 30–40 year-old needs 1.17 times the contrast to see as well as the 20–30 year-old average at the same luminance level. Figure 3 shows the comparison for age group 40–50. Here the contrast sensitivity multiplier is 1.20. The curve fits the data well except at the lowest luminances which are not relevant to interior illumination levels. Figure 4 shows a factor of 1.86 for age group 50–60, but here we see a definite change in the shape of the curve, although this is most pronounced at the lower luminances and may still be close enough to the same shape above 0.29 fL. (1 cd/m^2) to

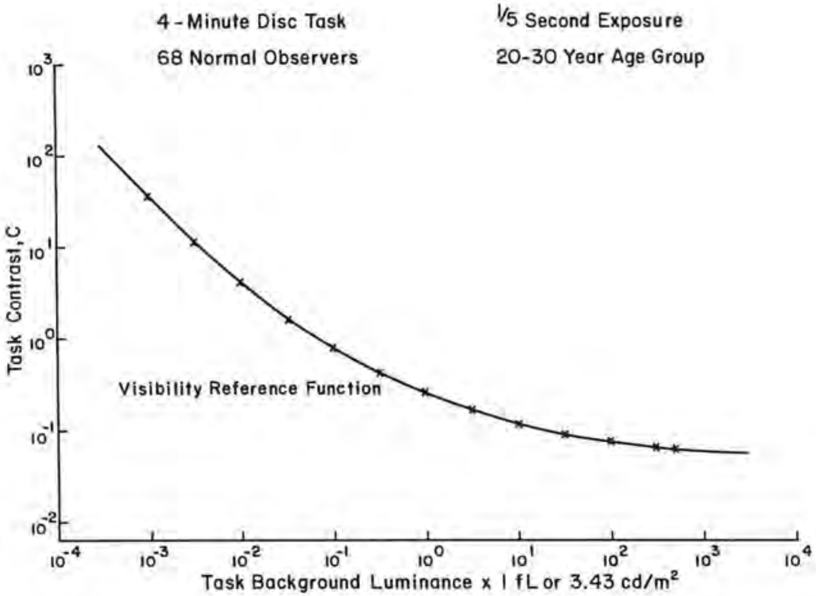

FIGURE 1.—Visibility reference function (20-30 year age group).

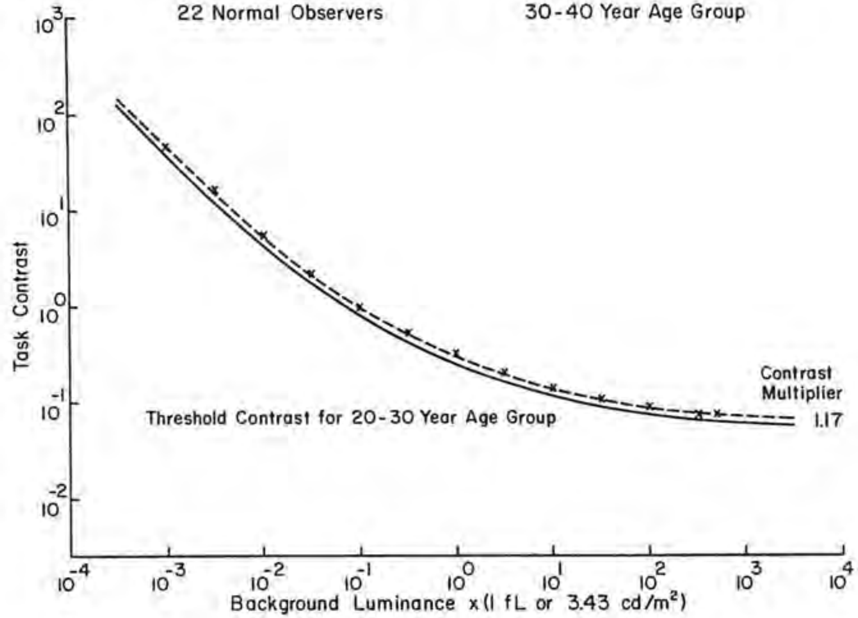

FIGURE 2.—Contrast sensitivity function for the 30-40 year age group compared to that of the 20-30 year age group.

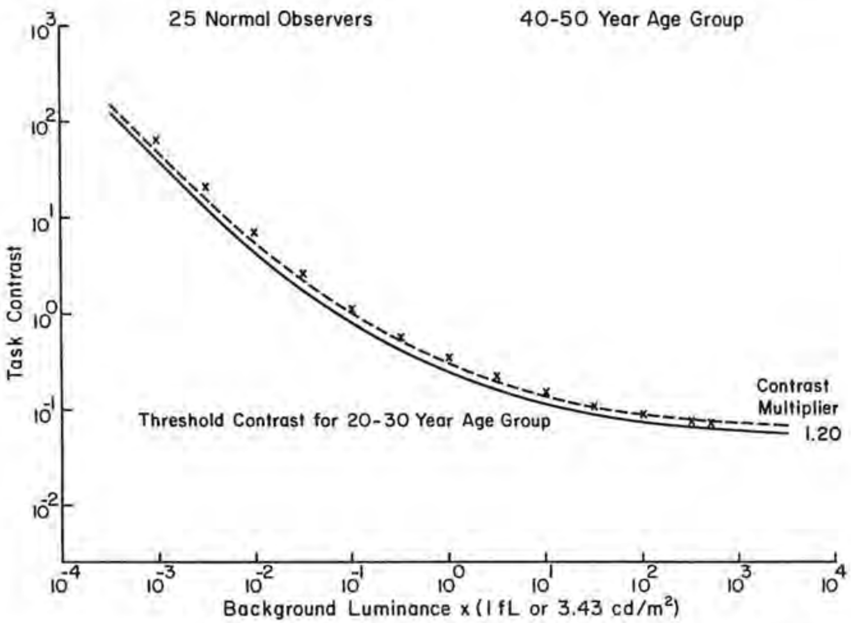

FIGURE 3.—Contrast sensitivity function for the 40-50 year age group compared to that of the 20-30 year age group.

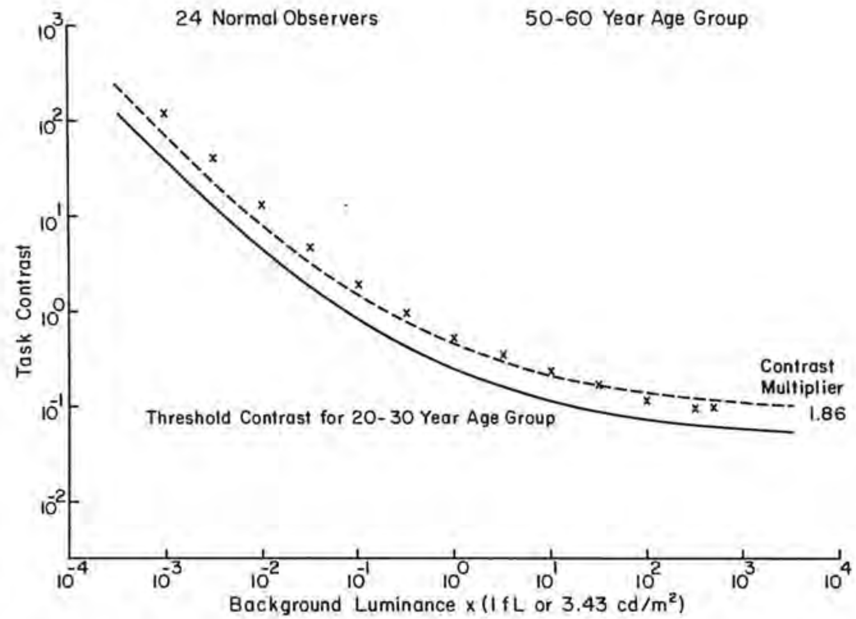

FIGURE 4.—Contrast sensitivity function for the 50-60 year age group compared to that of the 20-30 year age group.

allow us to use a single multiplicative factor for engineering purposes. Figure 5 shows the data for our 60–70 year-olds. Here the data are definitely not well fit by the reference curve. The best fit yields a result showing that these observers require 2.51 times the contrast to see as well as the 20–30 year-olds at levels of interior illumination. Figure 6 presents values of the contrast multiplier derived from the method of curve fitting shown in the dashed curve constructions in the preceding figures. These contrast multipliers represent average values for all luminances equal to or above 0.29 fL. (1 cd/m²). We see that the contrast multiplier varies rather slowly with age up to about 45 years and then shows a rapid increase with further increases in age.

To this point we have considered only average contrast sensitivity data for observers in each of our age groups. We may examine the data for individual members of each group in order to estimate variations to be expected in the population of observers of various ages. Again, we have used only the data for 0.29 fL. (1 cd/m²) and above. Figure 7 shows the proportion of observers in the 20–30 year-old age group requiring a given contrast multiplier to achieve equal contrast sensitivity to the average of the age group. This and the following graphs (Figures 7-11) show the cumulative probability as a function of contrast multiplier for observers in a given age group. The ×'s are the cumulative probabilities computed from the data; the solid curves are the normal frequency functions represented by the probit line fitted to the data points. Since the probability data found to be described by normal frequency functions in terms of $\Delta \log C$, the solid curve in this and the following graphs is skewed on a linear scale of contrast multiplier. The meaning of the figure can be described as follows: use of average contrast data for observers of a given age group provides exactly 50% of the observers in this group with the level of contrast discrimination defined by the task required of them, in this case, just barely detecting the 4-minute disc presented in 1/5-sec. exposures. Contrast multipliers may be used to compute the level of task contrast needed to provide different proportions of the population of observers in a given age range with this standard level of contrast sensitivity. Contrast multipliers less than 1 provide less than this level to less than 50% of the population, whereas a multiplier of more than 1 provides the standard contrast sensitivity to more than 50% of the observers. Figure 8 shows the proportion of observers of age 30–40 requiring given contrast multipliers to provide equal contrast sensitivity to the average of their age group. Figure 9 shows the same for age 40–50. Figure 10 shows the proportions for age group 50–60, and Figure 11 shows the distribution for the 60–70 year age group.

Figure 12 shows observer variability as a function of age. Sigmas of the log normal distributions have been corrected for sample size to provide an estimate of the population of a given age group. Here we see in general an increase in variability as a function of age except for an unexpected decrease in σ log for the age group 60–70. A possible explanation for this may be that, by this age, many of the subclinical optical defects which may be causing variability in the younger groups have become manifest. Since we have eliminated these observers from our sample, we would accordingly have reduced the variability. We have used the smooth curve representing the value of the contrast multiplier as a function of age and the smooth curve in this figure representing the value of σ log as a function of age to define contrast multipliers for different proportions of the population of observers of various ages.

Figure 13 shows the importance of these individual differences in contrast sensitivity in the setting of our interpretation of standards of illumination. Figure 13 returns again to the visibility reference function; i.e., the average contrast sensitivity as a function of luminance for the 20–30 year age group for the visibility reference task, a 4-minute disc exposed for 1/5 sec. This is represented by the solid line. The bell-shaped curve, which should be in the third dimension, shows the distribution of contrast threshold curves among different individuals in this reference population. The dotted lines show the curves for the least and most sensitive individuals. The significance of these individual differences becomes obvious when one selects some particular criterion visibility level such as VL8 which is the upper solid curve in the figure and the one incorporated into the present U.S. lighting standards. This visibility level defines the ratio of the values on the two solid lines in the graph, which is the distance between them as plotted here. The

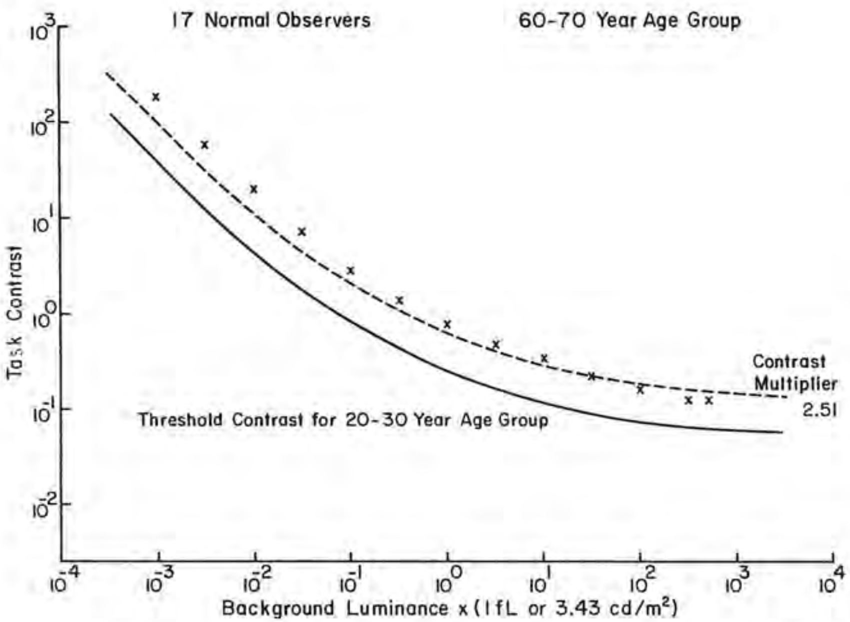

FIGURE 5.—Contrast sensitivity function for the 60-70 year age group compared to that of the 20-30 year age group.

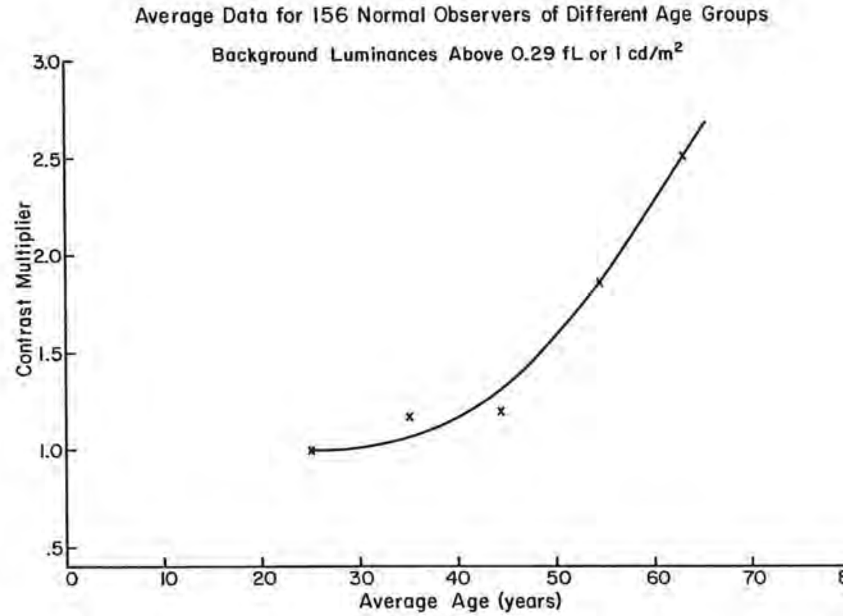

FIGURE 6.—Contrast multipliers required to fit the 20-30 year age group threshold contrast curve to that of other age groups at background luminances of interest in illumination specifications.

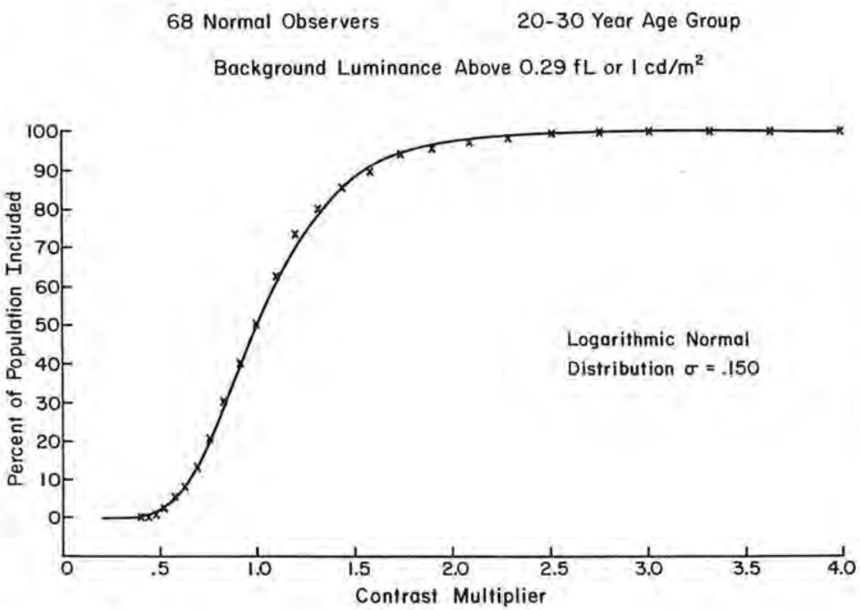

FIGURE 7.—Contrast multiplier required to achieve average contrast sensitivity of group (20-30 year age group).

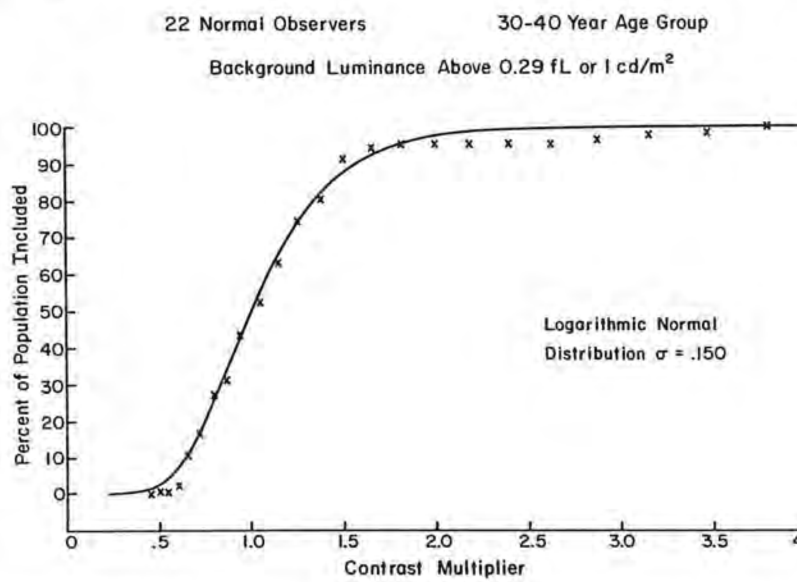

FIGURE 8.—Contrast multiplier required to achieve average contrast sensitivity of group (30-40 year age group).

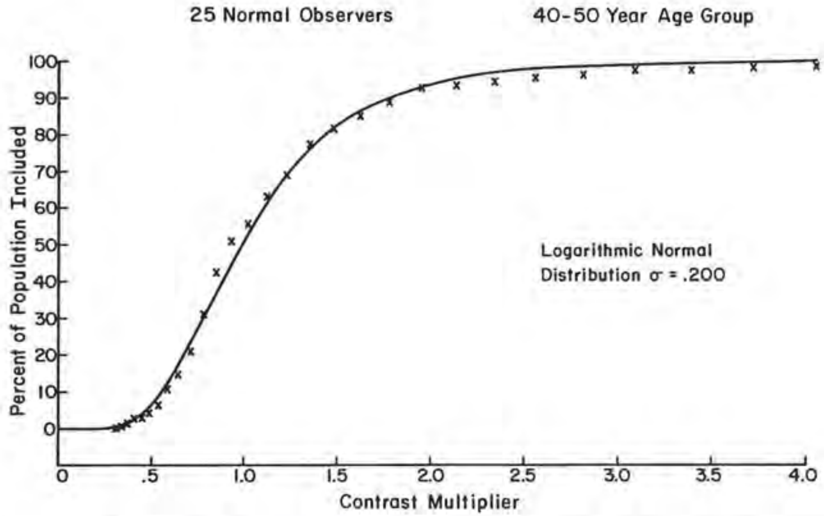

FIGURE 9.—Contrast multiplier required to achieve average contrast sensitivity of group (40-50 year age group).

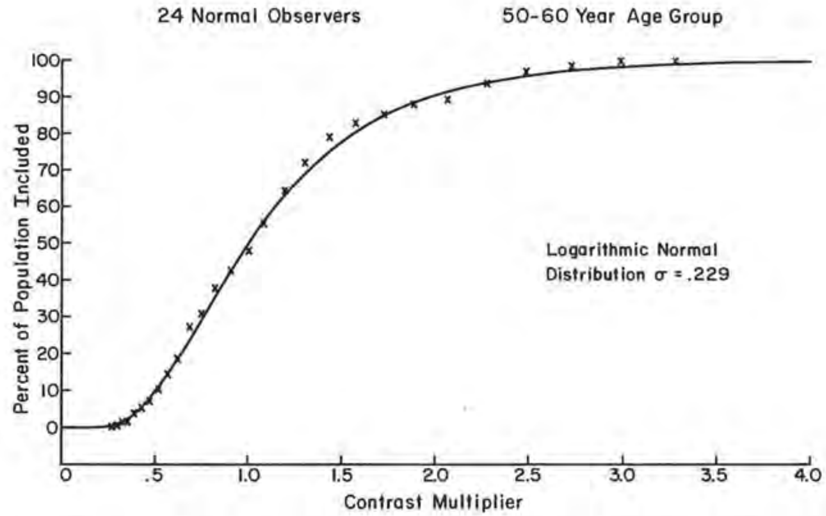

FIGURE 10.—Contrast multiplier required to achieve average contrast sensitivity of group 50-60 year age group).

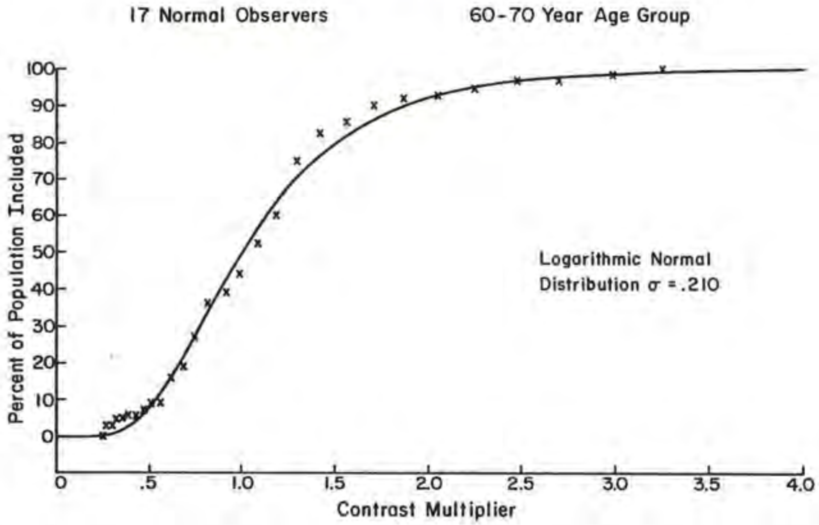

FIGURE 11.—Contrast multiplier required to achieve average contrast sensitivity of group (60-70 year age group).

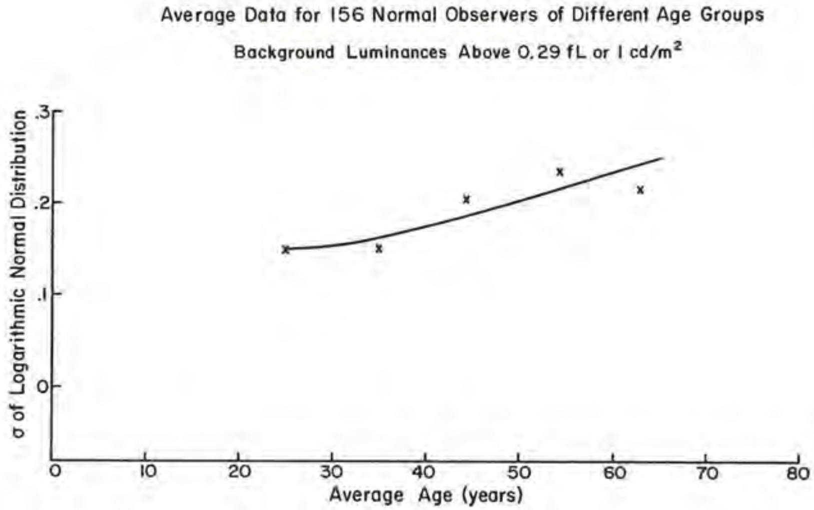

FIGURE 12.—Observer variability for the age groups tested.

distances from the threshold curves for the extreme individuals (dotted curves) to the VL 8 curve are not the same as the distance from the reference curve to the VL 8 curve. Thus, it is clear that these individuals will be provided a visibility level either lower or higher than that provided the average observer by the lighting recommendations. Figure 14 illustrates the effect on the visibility level (VL) of the average difference in contrast thresholds between two different populations, one the reference population of average age 25 and the other population of average age 50. The solid bell-shaped curve is the one shown in the previous figure and represents the range of individual differences among members of the reference population. The dashed bell-shaped curve represents the range of individual differences in the older age group. Note that, although the distributions of thresholds for individuals in these two populations overlap, the average threshold contrast is higher for the older age group. Thus VL 8 for the reference population would actually correspond to VL 5.1 for the average observer of the older group. Figure 15 shows the full data for all 156 observers in our study. Again the bottom solid line is the visibility reference function or the average contrast threshold curve for the 20–30 year-olds. The two dashed curves show the least sensitive and most sensitive individuals. Each bell-shaped distribution represents observers in a decade of life with the 20–30 year group the lowest, the 60–70 the highest, and the others in between. Note the large overlap in the distributions. Again we can see the great significance of these individual differences with reference to a particular criterion visibility level, in this case VL 8, the upper solid curve. Reduced sensitivity shows up on the graph as the need for increased contrast or equivalent contrast. Thus, visibility level will be reduced for observers having less sensitivity than the average observers in the 20–30 year age group whose thresholds were used to define visibility level. Observers with greater sensitivity than the reference population will have a greater suprathreshold visibility than the given value. It is clear from this figure that this effect is a very large one. Indeed, the least sensitive observer will have less than threshold visibility at VL8.

Figure 16 illustrates a more useful form of the population data. Here we have plotted the percentage of the 20–30 year old reference population having a contrast sensitivity multiplier equal to the value on the abscissa or more. 50% of this population has a contrast multiplier of 1 by definition since this is the visibility reference population. This curve can be used to evaluate the visual performance to be achieved by different proportions of this population for any value of effective visibility level which might be selected as a visibility criterion, simply by multiplying the contrast sensitivity multiplier by the criterion VL or visibility level. This will give suprathreshold factors for different proportions of this population for the criterion visibility level. How this can be applied is illustrated in the next two figures. Figure 17 shows the same kind of a curve for a population extending from age 20 to age 70 with proportional representation in accordance with the 1970 U.S. census. Now suppose we want to know the effect of the present criterion Visibility Level for lighting standards in this country on this population. We simply multiply the Contrast Sensitivity Multiplier by VL8 and can then plot a graph such as Figure 18 which shows the percentage of individuals in this normal population attaining a given suprathreshold factor or better when the criterion VL is 8. Referring to the solid line on the graph, it can be seen that 27.8% of this 20–70 year old normal population have individual suprathreshold factors equal to or greater than VL8. The average of the population has a suprathreshold factor of 5.7 instead of the recommended 8.

The dotted line on the graph shows the result of changing the criterion visibility level from 8 to 7.29 which represents a cut in illumination levels from 100 down to 50 fc. In this case only 22% of the population has VL 8 or better. The average VL is actually only 5.4. Thus, 6% more of the population will not have the criterion visibility level.

Thus we have developed a technique by which you can see our present best estimate of the effect of a change in the criterion effective visibility level on any population of interest.

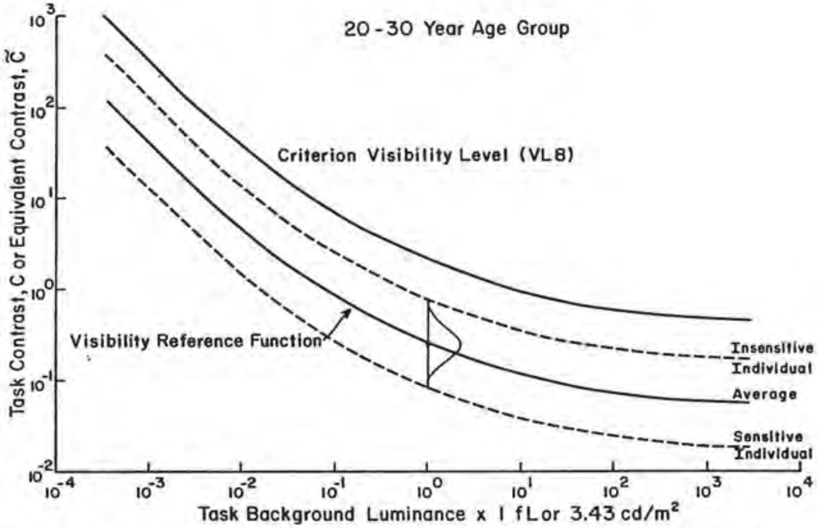

FIGURE 13.—The effect of individual differences in threshold visibility among 20-30 year olds on the significance of a criterion visibility level.

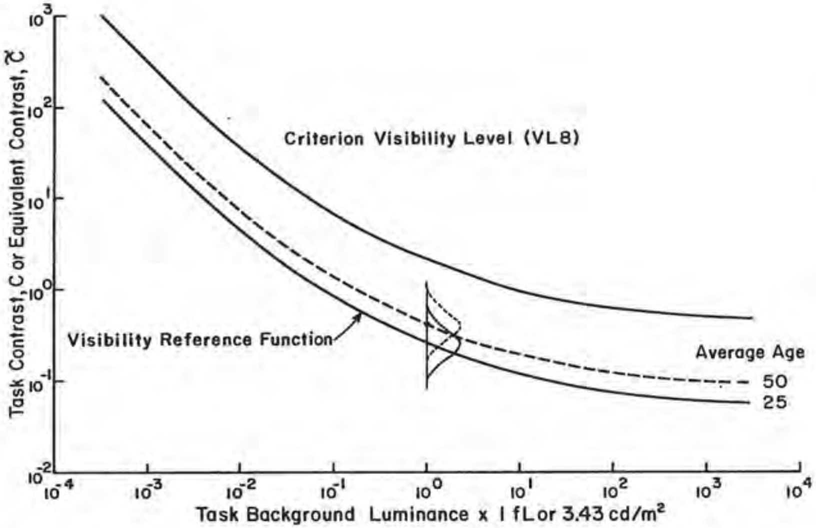

FIGURE 14.—The effect of an average difference in threshold visibility between two different age groups on the significance of a criterion visibility level.

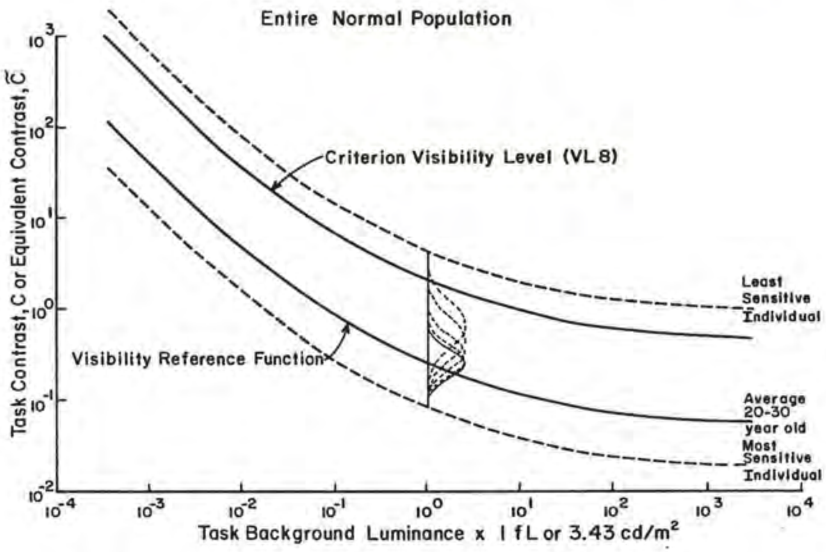

FIGURE 15.—The effect of individual differences in threshold visibility in the entire normal population on the significance of a criterion visibility level.

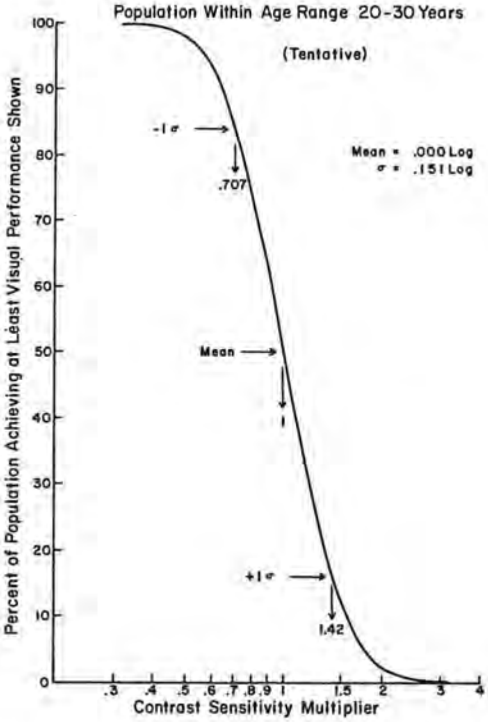

FIGURE 16.—Percentage of reference population having a given contrast sensitivity multiplier or greater.

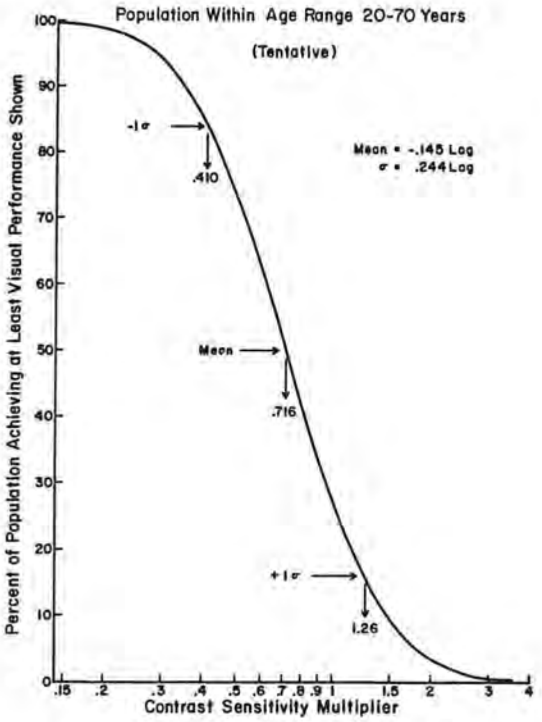

FIGURE 17.—Percentage of total population having a given contrast sensitivity multiplier or greater.

Dr. Blackwell: Now, thinking that the thing you really wanted to know about was not performance but health, we managed to get records of what it is you do when you give an observer different levels of suprathreshold factor. We have used our Purkinje Image Eye Tracker, developed by Stanford Research Institute, and had one observer first obtain her own threshold for a particular test object, and then we measured her ocular motor function as a function of how far above that threshold we were. We started with a visibility level of eight, which is the one currently used in the IES system, and systematically reduced the visibility level until we got down to two, the point at which we say she should barely see the target all the time; and we measured two classes of ocular motor responses. Incidentally, we got some symptomatic complaints par excellence as our observer told us what we had not dared to ask about how she felt about our low levels of visibility.

The first of these we used—I am sorry, Dr. Fry, maybe it is not a good measure, but it sure is a sensitive one—was steady fixation. This was Dr. Hebbard's task exactly; and what we did was have an observer look at a single four-minute spot of light which we had previously measured threshold on using the CIE system. In that case, we put on fixation lights. Then we took the fixation lights away and had one dot in a large screen, started with a visibility level of eight, and told her to steadily fixate it. These are the results of the X and Y coordinates of her ability to fixate. This is an extremely fine machine and we had just gotten it and it measures—these excursions are about six minutes of arc total extent and this observer is a very good observer and able to maintain excellent fixation—but what it means is that—remember the Hebbard experiment? The graph is a time scan. This is the X and Y coordinate of a system in which, if there were perfect stability fixation, the things would be two straight lines. The observer is told to look at a dot and hold her two eyes directly on the dot. These are not two eyes. These are one eye. The machine measures by means of two servos, infrared, one locked onto the first Purkinje image, one picking up the fourth Purkinje image, and translating the motion needed for *servo optimization* of the signal and of XY coordinates, put onto an oscilloscope. By measuring the amplitude we are able to determine the extent

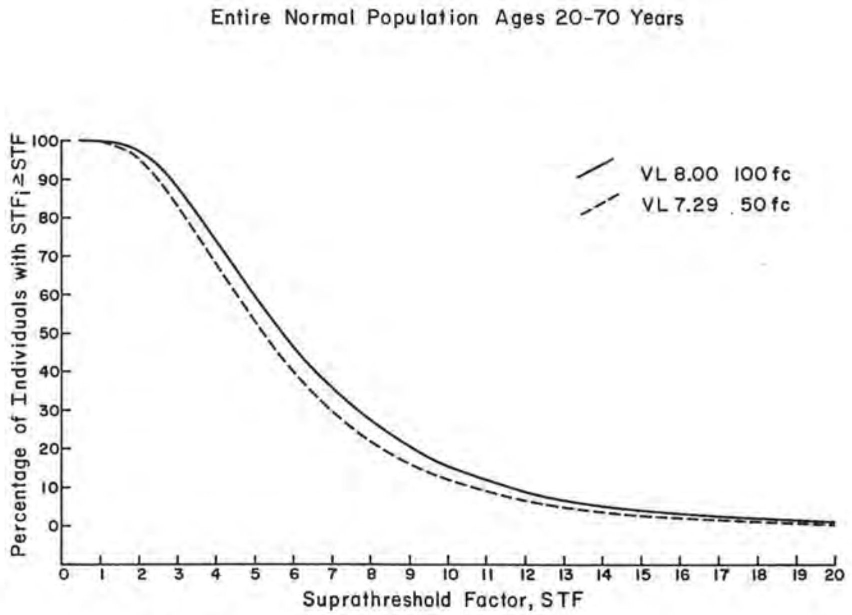

FIGURE 18.—Percentage of total population attaining a given suprathreshold factor or better at VL8 and 7.29.

to which she can maintain steady fixation.

Hebbard's experiment has been discussed so much. It is shown here, together with my interpretation of it. I took Hebbard's actual visual display, which was the little ring of light. He told his observers, as I told mine, to look at this steadily. Using the contact lens method that you saw a photograph of, he recorded the extent to which you could not do this, the extent to which the eye oscillated in trying to hold steady fixation. He varied both the contrast of the target and the light level by a factor of one hundred to one. Later, I took a visibility meter and measured the visibility of this particular display and replotted his data in terms of what was then called the relative visibility factor. To get it into modern language, one on that scale is VL 8. This was put in terms of the IES method.

This showed the same phenomenon that I am able to show you here more directly with my records; namely, that if you begin to cut the visibility level below eight, there begins to develop an inability to maintain an accurate sharp focus. Reducing the information to the servo system, opening up the loop, and the thing starts to chatter. And that is what that shows. As the visibility level goes down from eight, which is one on the scale, to 4 which is 0.5 on the scale, there has been a certain increase in the variability of steady ocular fixation. Now, we have here the records so you can study them to show you what this looks like in terms of time. It turned out to be very interesting indeed because you will see that what happens is that one can do this reasonably well for a limited time when visibility level is cut but, then, the system goes berserk and completely loses ability to do it. That is to say you get fairly good behavior for a while and, then, suddenly a great big excursion that puts the record off the paper and the eye tries to come back and do it again, in short, a big movement. The time per inch is one millimeter per second. I also have some nice strip charts that are at five millimeters per second for us to study tomorrow. The frequency is very rapid. It is physiological nystagmus that we are picking up. I am sorry. I just wanted to say I had it; tomorrow we can study it. I wanted to say that we did these experiments to find out the consequences in ocular motor function of changing visibility level. This experiment had been done years ago but had the defect that we did not have the same observer measure his own threshold. This was done by the method that I measured the visibility of the task long after he had done the experiment and I used as a reference point the average twenty to thirty-year-old observer. The direct way to do it is to take the same human being and the same machine, have them measure their own threshold, and, then, deliberately increase the contrast above that and find out exactly how it comes out. What I am trying to say is that I have here records that show that, indeed, this happens; and it happens about the same as is shown on the graph when I do it in the most sensitive and direct way.

I can show you tomorrow, with more time, two interesting aspects of the behavior. One aspect of the behavior is that at VL 5 things begin to happen; at four it is much worse; at two it is almost impossible, as you might imagine. With the steps I took—eight, six, five, four and two—by the time I got to two, the observer is almost unable to see it. There are long periods in which she has lost it and her eyes move so far as to go off the record. Then she will find it again and we are able to latch onto her with a machine and go again. So one aspect of it is that performance is not uniformly bad over time. You do pretty well for a little bit and then go and lose it altogether. So there is a *temporal* factor that Hebbard's data did not show because he did not present them in that form.

And, secondly, the most interesting thing was that this behavior deteriorates rather quickly. If you measure it for only five or ten minutes at a low visibility level, the observer does, in some ways, remarkably well. But make her do it for fifteen minutes and two things happen. One, the behavior is dramatically worse. I have records — the first time I did it and after fifteen minutes I did it again; you can see for yourself. Finally, she began to lacrimate and to complain. Now, at what point, exactly, did she begin to complain? Surely at VL 4 she complained. VL 2 was impossible. VL 5 and 6, some complaints. But my instinct was that VL 4 or somewhere around there is where trouble would start to occur. Well, this, of course, is not proof; but it does show that it is not a difficult matter to find out that, if you begin to reduce visibility much below eight, there is a change in the ocular motor performance.

Now, I did one more experiment that had never been done before, which I thought might be a better test, since I knew there were some objections to the steady fixation test. We had her look from one point in space to another. In the first experiment I have here, we had her looking from one Landolt ring to another when they were 1.75 degrees apart. You can look at the smoothness with which she made the shifts. We said, "Left, right, left, right," and did it at various visibility levels. The data show the same phenomena as before. As you go down in visibility level, suprathreshold factor for her, you can see that she begins to do this much less well and, again, after fifteen minutes, much, much worse than before; and, again, she begins to make some dramatic complaints.

We did this Monday. Tuesday, the last day we had, we did one other experiment, because once she anticipated me — I did not say move and she moved. I began to wonder whether she was not doing spuriously well by paying no attention at all to what was supposed to be seen but just making the same movements in magnitude from memory. Subjects are rather good at this; you have to watch it. So I set up, the next day, five dots, better than Landolt rings because there is an ambiguity in Landolt rings about where you should direct your eye, at the middle or the edges or what. I measured the threshold for these, repeated the experiment—I have long strips I can show you tomorrow — and got essentially the same results, only in this case I completely kept her from guessing what I was going to ask for by changing my commands. I had her look at the center of the array and go either up, down, left or right and kept mixing them up. But the conclusion is the same. You can definitely find out that, when you begin to cut the V.L. down, certainly to four, five and six, there definitely is a loss in the ability of the ocular motor systems to function and there are symptomatic complaints. She lacrimated, under all these experiments, when the visibility level was about four.

Now, the interesting thing is, if you can believe what we have presented to you here, it says that there are a lot of people in the population who should have similar problems. There are, in fact, some that will have similar problems at IES recommended illumination levels. There certainly are a few more, at least, who would have complaints at reduced luminance levels. And, in a sense, then, this was, if you will, a kind of an effort to see if we could believe those people who came to the GSA and started all this off by saying that they felt the light levels were causing them symptomatic complaints. We have not proved this; but, in a sense, I think I satisfied myself—two more years of research would probably prove it—that very likely some people in the population at current light levels, and some more at reduced light levels, have the basis for symptomatic complaints, because we are not giving them enough visibility above their threshold to drive their ocular motor systems in an adequate way. What we need, of course, is to have a very accurate definition of the point at which we get into trouble and I can not claim I have that. We would have to have lots of observers; we would have to see whether this is the rectifying variable, that, if we took observers with different sensitivities, they all had ocular motor troubles at the same suprathreshold factor. We expect the ones with low sensitivity, who are older, to have trouble sooner, if anything, because our dynamic performance data on older people show that they lose more than just sensitivity as they get older. They lose ocular motor motility as well.

And so, in a sense, we think that this has proved to us to be a useful way to look at the problem. What do you do, from a performance point of view and a symptomatic point of view, if you cut light levels? We think the individual differences in observers are astonishingly large. This has been confirmed by three different experiments by three different people. Vos and Bauman and Lazet did one, Smith did another, and my wife and I did the third. And they all showed the same thing; these differences really are there. They are not methodological; they are not people not paying attention to the experiment; the sensitivities really do vary as much as this and do have a direct effect on performance. We measured forty-eight people, measured their sensitivities and measured their performance and have shown that these sensitivity changes show up directly in performance. People differ in performance, also, by taking account of their threshold differences, which reduces the variance of the data enormously. So we think this is really what you are doing when you cut your light levels in half.

Now, I should say, and we can expand on this tomorrow, that one big catch is that we have talked entirely in terms of a visibility level criterion. You know the way the thing works, you pick a visibility level criterion—eight, seven, whatever it might be—let us say that Great Britain picked 7.29 and the U.S. picked 8. Now, having done that, you do not get a light level until you have done one thing more and that is to decide what visual task is important. Now, let us suppose that there are villains in the audience with commercial interests. If they pick the right V.L., it is still going to influence the light levels a great deal by picking unreasonable tasks. And so, I just remind you that whenever the V.L. part is what we are concerned about, the selection of tasks, also, has a large effect on illumination levels. Bold print requires one; dim print requires a hundred footcandles. Now, someone else has to decide, not us, what reasonable tasks are. But, again, to us, the visibility level is what lighting is all about. We recognize there are other aspects of it covered by suprathreshold clarity, such as the pleasantness of lighting which are not included. But we believe we have some feel now for what you are doing by cutting light level.

Incidentally, you might be amused, as one last remark, the university, of all things, asked me if I would please advise their "Energy Saving Department" on how and where to remove light bulbs. I suspect that they wanted me to bless their taking out half the light bulbs in the university. I soon discovered that is what they really wanted me to do. They said, "You must tell us tomorrow; we have to start tomorrow. You have no time. What do we do? We start tomorrow. We want to save half the energy in the university." So, looking at my wife's curve showing the abrupt change at forty-five age, I made one simple rule which they have followed. They reduced the light level differentially for those below forty-five years and those above. Fortunately, in a university, the populations are rather separate; most of the professors are over forty-five and the students are a great deal under. And so, all the cut is being taken out of the young age group in classrooms and the professors' offices are being left alone. I still think that is not a bad day's work, and it was the best thing we could do under the circumstances. Dr. Weale's data provided partial explanation. Older people need more light, as he said, a factor of three. Well, then, in a sense, I have given them twice as much by not taking away what they had. I did not realize the number was three; but, in a sense, I did not do a bad job of thumbnail engineering.

ILLUMINATION LEVELS AND SAFETY

John V. Grimaldi, Ph.D.

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 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 footcandle 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 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-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 sentences 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.

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 investigated 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 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 occurrences. 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 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 ceilings, 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 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.

WHAT ARE THE LIGHTING NEEDS OF THE OCCUPANT (WORKER)?

Gary T. Yonemura, Ph.D.

Dr. Yonemura: Actually, I am going to reiterate much of what has been talked about before and I think I can serve a function in the sense of emphasizing what we have been talking about. I am a psychophysicist; I am not an architect; I am not a designer; and I think most of us here are in what is called the hard sciences rather than the design sciences. I think we should be made aware of this.

Lighting engineers feel user requirements are fulfilled when physical or physiological needs are satisfied. Furthermore, they assume they know what the user's requirements are; that is, what the user wants the luminance environment to perform, and from this assumption proceed to develop standards. I have seen this, I think, in the last day or two.

When discussing quantitative and qualitative requirements of lighting, user requirements are generally based on task recognition or task performance. We psychophysicists apologize for this. We apologize and say the other side is important and forget about it. Is this acceptable? For example, we ask what must the luminance level be for satisfactory visual task performance? How does the size of the visual stimulus affect task performance? What is the tradeoff between contrast and luminance level for task performance? The emphasis is on the physiological capacity and limitation of the observer or user.

This is not to imply that psychophysicists are not aware of psychological effects. They can and do influence visual task performance. But these psychological effects are treated as undesirable parameters that must be controlled. If we control it, we can ignore it. Even among psychophysicists, disagreement exists as to the kind of visual task and the procedure that are appropriate for evaluating lighting needs. Rather than discuss this problem, I would like to proceed to the more general problem of physical, emotional and intellectual factors as the basic considerations in user lighting requirements.

Nonvisual scientists, such as architects, interested in the assessment of lighting needs, insist that emotional and intellectual needs are just as important as the physical needs. These psychological requirements are not restricted to aesthetic ones. There is one area involving subjective evaluation of the luminance environment for which quantitative recommended practices are prescribed today. This is discomfort glare which was mentioned yesterday. It is important to remember that we are not talking about disability glare. The experimental procedure followed in obtaining visual comfort probability (VCP) was not task performance but subjective evaluation by observers. The criterion for visual comfort probability is not how the glare source directly affects task performance, although there is an assumption that it indirectly affects task performance as a consequence of psychological effects resulting from dissatisfaction with the visual environment.

It may be that what is today treated as subjective preference may be correlated with physiological response in the future. We had two examples of this yesterday: Dr. Fry's work on discomfort glare and its relation to a cyclic opening and closing of the iris, and Dr. Blackwell brought up the effect of fixation and the probability of fatigue resulting from that. We do not know what the answers are, but he may be right.

What I want to bring out is the necessity to more carefully assess user requirements. Let me take another example from the subject being discussed at this symposium, lighting health and safety. A specific question would be: What should the level of illumination be in order that the environment be safe and healthy for the worker? As visual scientists, when we think of safety and lighting for circulation areas—let us restrict ourselves to that—we conclude that the designated areas should have enough illumination that the worker can clearly see any obstruction. This takes care of safety. What is the second half of the equation, health?

For health, I think we should include both physiological and mental health. Is the level of light recommended for safety the same level that will be recommended when psychological consequences are considered? The worker may have enough light to adequately see any obstruction, but he feels insecure in a dimly lit environment, a psychological factor. How much consideration should be given to the psychological need as opposed to the physiological one? This can lead us to another topic, security lighting, which we have looked into a little bit.

What is the function of security lighting? Is it to deter the criminal? Is it to be adequate for observing a criminal act in progress or even require that the illumination level be sufficient so that the felon can be identified? I think that this is Mr. Crouch's criterion. Or should the criterion be that level that makes the occupant feel secure? The obvious solution, which is to take the criterion with the extreme level, has difficulties. The extreme level may prove detrimental to another criterion; and, furthermore, we no longer are living in the age of cheap and plentiful energy.

We can say this is a policy question—this was brought up this morning—and not the responsibility of the engineer or scientist. But, for the lighting researcher, it is a pertinent question that he must answer. He can not say, "I'm only interested in physiological needs." The total user reaction is the problem. Should luminance levels be set according to what the subject feels is the required level, although this may be different from that obtained by task performance techniques? Again, this problem cannot be brushed aside as one of policy. The question of the importance of the emotional and intellectual needs must be answered. This decision can significantly affect lighting design. If there is a discrepancy between luminance levels for visual performance and preferred levels, what should the criterion be?

Yesterday, Dr. Weale talked about the British standard and he mentioned the fact that it was partly based on performance and partly based on psychological needs, which, in this case was preferred levels. And, if my recollection of the British standard is correct, the preferred levels were much higher than the performance requirements and therefore, they compromised. So they had both needs and they picked an average level. I do not know that I accept a compromise solution in this case. I think it should be one or the other. We should decide what the criterion should be and use that. If the user-preferred level is the most important criteria, then use that. If it is task performance we are interested in, then use that and ignore the more psychological needs.

Now, in summarizing, the purpose of this presentation was to introduce another side of the lighting story, the side that is opposite from mine. I am trying to present the views of the designers and architects. More time and effort should be spent in determining what the user requires of the lighting systems. We think we know what the user wants, but I have my doubts. Should task performance be the basis for recommending light levels, or should equal consideration be given to emotional and intellectual needs, attitudes, impressions, moods, et cetera. A lighting system satisfactory in terms of task performance may not necessarily fulfill emotional and intellectual needs. A visual scientist will unequivocally state that a ratio of peripheral and task luminance of one will be the optimum for task performance. But a designer will insist on modeling considerations, a proportionate amount of light and shadow for a healthy psychological environment.

This is not a new problem. Dr. Cogan has been stating for the last thirty years that psychological fatigue can result from a poor luminance environment with no evidence of organic harm to the eye. Dr. Blackwell has shown that maybe there is some kind of a temporary difficulty; but I do not think that is the problem that we need to attack. How it results is not the question. How important it is to the user is the question that should be answered.

The suggestion is that a real effort be made to resolve the standing of these psychological criteria rather than give lip service; that is, say they are important but do nothing about them. Let us get the data to better identify the variables and then deal with them in a meaningful way when designing lighting systems. We have half-hearted efforts being undertaken today to investigate these factors.

I hope I have not left the impression that I am fully convinced that emotional and intellectual needs in lighting have just as important a role as physiological needs. I personally feel that many of these psychological factors are highly personal and that, when quantified, the range may be greater than zero to some higher level, but range from negative to positive values. For example, in color harmony, for the same room being used for the same purpose, some will like what we call circus colors—that is, psychedelic colors—combinations of highly saturated and complementary hues. Others will insist on color combinations with little chromatic contrast or what we will call conservative colors, the opposite extreme. The present popularity of multidimensional scaling has increased interest in the investigation of the more subjective aspects of the environment. But we must be careful, we must quantify the dimensions extracted and identified by the multidimensional scaling techniques. If these variables, upon quantification by experiment, show a highly diverse population—that is, a very large standard deviation, probably indicating the highly personal nature of the dimension—any attempt to utilize them as a criteria for a standardization of lighting design is, I think, hopeless. On the other hand, we may isolate variables that most observers react to in a similar fashion within a reasonable range. A dimension of this type can be used as criterion for standardization purposes.

Well, I have raised many questions and given few answers, but my original purpose was to broaden our outlook when we consider lighting design. These factors have been mentioned and have been used by lighting designers. Now, the question is: Should researchers, building managers, and regulatory boards continue to dismiss these concerns as being unscientific, or should we adopt the opposite viewpoint and consider these issues as a challenge to our experimental ingenuity and try to tackle them?

DISCUSSION

Dr. Weale: I was very interested in Dr. Yonemura's observations; and, whether the U.K. has arrived at a compromise between user and performance, does not, I think, matter very much because it involves an arbitrary decision and any decision which is reached in this field is bound to be arbitrary. Even if this meeting, or any other meeting, does not adopt a particular compromise which has been adopted elsewhere, they have to adopt some other compromise. That is what has transpired from everything that has been said. If you have a ninety percent level of acceptance, this is an arbitrary decision. If you make it a fifty percent level of acceptance, it is still arbitrary. I have very strong reservations about depending on the user exclusively. I pointed out yesterday that the user who drives feels happiest when he has had a little alcohol. By that token, no doubt, this meeting would recommend that you should not be allowed to drive without some alcohol. In addition to light being used for safety, work and pleasure, it also is a commodity to be sold. The user can also be brainwashed. I need hardly remind you about what can be done in connection with advertising prunes. The same might apply to light. If you are going to tell the user he ought to want more light or less light, it does not matter which way we go. The user can be conditioned into what you want him to do. And it seems to me if any recommendation is going to be based on medical, physiological, and generally scientific considerations, then the user comes into it only on a marginal basis. I quite agree that an environment should be pleasant, but one ought to count the cost. The pleasantness of an environment can be controlled by paint; it does not have to be controlled, necessarily, by luminaires.

Dr. Yonemura: I think that you are saying that what the user wants is immaterial and that it is what we think is good for him that should be the criteria. We have a lot of objections to this. Granted that most preferred levels are based upon experience and learned, but is this immaterial? What the people want, a lot of them, is what we should work for or strive to obtain, and, in many cases, it is bad for them; but, still, this is what they want. Should we re-educate them to show them how bad it is, or should we accept their wants and desires as being the real needs?

Dr. Weale: I did not say it was immaterial. I would not like to be reported as saying it was immaterial. My word was "marginal." The use of the word "marginal" was contingent on the assumption that the problem is controlled by economy. It seems to me, if one is in a situation where one has to economize, that one way of bringing this home to people is that they can not have exactly what they want. This is what all this is about.

Dr. Halldane: You would not need standards, effectively, if that was the situation.

Dr. Weale: Quite. If you are going to limit it to arbitration, then you do not have to discuss it. It is like water, you can have what you like. You can have as much water as you like if you can find enough of it. If you go to Israel, I am told, you find that water is metered. It is metering of light we are talking about.

Mr. Caplan: If you are going to bring in the subject of economic benefit or the reduction in energy cost and so on, I think you have to start going into what we do in our planning of cost/benefit ratios where you may increase or decrease the cost of lighting, but your benefit may be reduced by reduction in performance and in worker activity. You have to balance these things out to have those numbers before you can make any intelligent decision as to whether the reduction in cost is worth the reduction in benefit.

Dr. Blackwell: I think that the key thing Dr. Yonemura was saying, I must agree with most strongly, is that we know a lot about performance. The reason is because it is relatively straightforward to measure and we had the basic methodological know-how when this all began. Psychophysics had a history of a hundred years first. So I would justify my life by saying I measured something I knew how to measure, knowing full well it was only part of the story.

I do not say bad things about multidimensional scaling; I look forward to an architectural psychology that will be helpful. I think there are some very bright people who are working on it. It is a very difficult problem and it may be, for the next year, we are not going to have it. But I think we will have in ten years or twenty years, certainly, a fully developed reaction to the psychology of lighting which may, indeed, modify rather severely the things we concluded before that. The problem, I think, is that we do not have it fully developed today. Now, can we, then, do anything without it?

It seems to me we said that there are fuller bases one could use for deciding about light, preference is one. Oddly enough, as I said yesterday, that leads to the highest levels. You can not justify two hundred footcandles, in my opinion, for many tasks, if any. But that is the level people gave when allowed to set a rheostat in Bodmann's experiment. Performance calls for lower levels. I believe it was said, and was generally agreed this morning with a few minor exceptions, safety probably would call for less yet; and I rather suspect that health will come lower yet. There is a kind of hierarchy, in short, of the light levels, I think, that will come out of different criteria. In a sense, I do not think we can afford user preference; so, in a way I think we can throw it out on the basis of simple economics.

Performance does happen to be the one on which we have the most information. The question is: Are there serious psychological factors that are violated by performance criteria? We have not had time to talk about the fact that raw illumination is meaningless. We hinted at it yesterday. Indeed, in the IES handbook, it says that you do not use illumination units at all; you do not use luminance units; you use effective luminance units in accordance with the CIE report, that is the International Commission of Illumination. My wife and I wrote it so we know a lot about it. This says that you just do not talk about luminance because the eye does not care very much about luminance. The eye cares ten times as much about other things. It cares about the contrast of the task. It cares about luminance ratios in the environment, even from a performance point of view.

The report is so valuable because it puts all these factors together in a straightforward, algebraic way. And, interestingly enough, it throws out as uneconomical most of the environments that people do not like. Now you might say that is a kind of accident, but I think not. People are not attuned to their own performance but they must have some sense of non-wellbeing when informed that their performance is bad. It does seem that an amazing number of the dimensions of preferred environment are handled by performance criteria alone. Later I would like to show you how we could try to use performance criteria to guide decision-making at the Federal level now. I am a reasonable enough man to know that we have to have a highly advanced technology, perhaps, for planning future spaces. It is here; we can do it beginning tomorrow. But we must have a very, very crude technology for evaluating existing spaces. I think we know enough to do both of those and to do it now.

I really believe that, if you are willing to say that, perhaps, if user preference is impossible, you then come to performance and, perhaps, that will take care of health and safety. I think I can make proposals that would not surprise you, perhaps, but might show you that your decision-making today is pretty good and might guide you in decision-making both at the crude level, which is for existing spaces, and at the more refined technology. In short, I would like to talk you into changing your rules only in a small way. Use CIE effective luminance instead of luminance.

Dr. Mead: Are we about to launch into an attempt to demonstrate that a performance measure is, indeed, the kind of measure that ought to be used in making a Federal decision? I wonder whether this is an acceptable measure?

Dr. Blackwell: With respect to considering performance criteria instead of something else, would you not say the sad truth is we do not have highly developed alternatives? And that the statement that has been made, which is, at the moment, if you satisfy performance criteria, you are undoubtedly going to satisfy the other two.

Mr. Crouch: We do not know that.

Dr. Blackwell: I think we do. Remember yesterday, I said—and Hebbard's data show this —that we would get optimum performance and there would be no justification, in God's green earth, for going above VL 8 as far as the ocular motor system is concerned. Hebbard's curve comes out absolutely flat. I think, myself, if you were to use a health basis alone, that it would probably be something of the order of VL 5, somewhere between four and six would be sufficient to avoid symptomatology. We have already established the fact that some people probably will have symptoms at either current light levels or those cut in half; and, of course, our hosts have given us the solution. Let us emphasize the use of supplementary lighting. It is true that Hebbard's data are, however, limited to a few subjects. We planned to do research on this; but, if you want to know where we stand today, all I can say is that, from everything we know at the present time, I am not surprised with the result that the ocular motor system can be driven rather well with something like two times the ninety-nine percent threshold.

Mr. Caplan: Are you saying that, in general, that if you satisfy a performance criteria, you will, in general, satisfy a safety criteria?

Dr. Blackwell: And a health criteria.

Mr. Caplan: I am just wondering, in the safety field, how often it is that when the performance level illumination necessary is very, very low, it will be below the safety level. I was in the Navy and I remember many times going out on watch at night, tripping over lines and one thing and another, but the actual level that you need for lookout duty and so on was very, very low.

Dr. Blackwell: Your performance included getting to the station without falling over the cables. I think we agree there are certainly cases where serious injury or death can result from an error.

Mr. Caplan: Mining is another example.

Dr. Blackwell: In those cases, one simply has to say performance and safety are one and the same thing. You cannot tolerate an error, it kills a man, or maybe you can. Let that be a political decision. I am saying that, by and large, moving aside special cases like this— which I think are relatively rare—what has been done by ANSI in setting levels of illumination for safety from one-half to five footcandles as well as OSHA's safety requirements reflects what Professor Grimaldi said, which is that, by and large, if you have enough light to satisfy the performance criteria—even Tinker's value, let us say, of twenty—you have more than enough to keep people from falling down stairwells. I think that is true and that is the point that I am going to make. I am saying that, in terms of a practical outcome of the conference, I think we are in a box, which is, we do not know enough about the other two criteria today to do anything more than to say we need to know more.

I would like to try to give the perspective that I think I see in it, using the only information we have. That is what engineering is all about. It is not ultimate truth; it is all that we know. I believe that this will take a little different shape, perhaps, then some of you realize. The CIE report changes the world as far as vision is concerned. I think it might be helpful to discuss what could be done with the performance criteria and see if you all agree.

Mr. Crouch: In my opinion, the CIE report is only in a draft form and it has not been sufficiently backed by evidence yet.

Dr. Blackwell: Well, Mr. Crouch, let me present the story on that. I am not speaking for the IERI. I am not speaking for the IES. I am speaking only for H. Richard Blackwell and a committee of experts from forty countries who do not care about the IES's opinion one way or the other. This is a scientific document. You may not wish to use it, that is the choice any practical body has. But I am here to give you scientific evidence, speaking as a college professor.

GENERAL DISCUSSION

Chairman Heins: At this time I think a brief discussion of performance criteria is in order and I would like to hear it. One point I would also like to have you comment on again, Dr. Blackwell, is your previous statement that for a VL of about five, performance considerations will probably preclude health and safety considerations in terms of avoiding symptomatology.

Dr. Blackwell: Be very careful, now, and remember that the nature of individual differences has to be looked at very carefully. Earlier my wife showed a graph which shows that, even with a VL 8 criterion, which leads to one hundred footcandles and up for the tasks that have been selected, some people are going to be operating remarkably near their threshold, primarily older people.

Now, those people, if it is true that, at a VL 4, 5, or 6—pick the number out of the hat until we get the final information—older people will have ocular motor symptoms at these levels. And I believe it is obvious that this is the case. Once you get below two, it is absolutely obvious. There is a percentage of people who will have less than ninety-nine percent accuracy of their detection if you provide light levels that give other people light they do not need because the individual differences are so enormous. I am just repeating what Dr. Weale said.

That being the case, this leaves open the problem, which is that you may not be able to be concerned about the worker whose performance is not the best. Are you concerned about the worker whose comfort or health is not the best because he complains? I suggested earlier that this might be how it all shakes out. When it comes to a performance criteria, you are not going to be able to worry about the insensitive observers. You have to say we will satisfy, perhaps, fifty percent of the entire population at what looks like a good, economical level. You can not do much better than that. I think I can show you that that is the kind of standard you will probably have to end up using. Now, you just have to ignore the fact that some people will not perform terribly well. But they do not perform well for other reasons, too. As I said, some are stupid and ignorant and all kinds of other things.

Now, you might want to say that NIOSH is concerned in a different way about the "marginal people"; that is, the ones that have a right to be in the environment but would find themselves with symptoms under certain kinds of lighting levels unless you did something about them. I would maintain that even current levels do not free you from this problem. I can tell you that, if you are a presbyope as I am, operating at low light levels, you can get awfully miserable sometimes if you have to work at a distance for which you are not in focus. Light has a beneficial effect by pulling down the pupil and the depth of field, as in a camera. That is the kind of variable that I think NIOSH should be concerned about. In short, I think we should talk further about the necessity to look at the health research for the extreme people because I think each individual counts—because he can complain to his congressman.

When it comes to performance, you are going to have to look at averages. That was the point that I tried to make before, that your criterion, in a sense, has to be different. It is not the same. People do not know that they perform less well in general. We have done the experiment. We brought people into rooms, changed the lighting, and had people fill out questionnaires in regard to how visible they thought things were, how comfortable they were, how well they liked the environment. We changed the environment of this particular classroom at Ohio State. We changed it from a rather bad environment, from our point of view, to rather a good one. What happened? People were not very much aware of the loss in performance. We can measure it, but it did not get through to them that their performance was less good. The comfort and general pleasantness of the environment came out loud and clear. So I think the argument that people know they can not see does not appear to be true. The eye is a rather subtle device and, unless there is objective evidence like making mistakes, bad decisions, or unless eyestrain or other symptomatology occurs, people do not seem to know that they are not seeing very well.

Chairman Heins: Can you give us an idea, in your opinion, based on your best estimate, as to what percentage of the people might suffer from symptomatology at the levels proposed by GSA.

Dr. Blackwell: In a sense, you have the information to prove me a good or a bad guesser, I think, because you know something I do not know, which is how many people complained to GSA and got this all started. This curve says that, at the order of current lighting levels cut in half, ten percent of the population is going to be operating at approximately a VL of 3. Now, this includes, of course, the entire age group from twenty to seventy in accordance with the census of 1970. Naturally, a disproportionate number of those ten percenters are the fifty and sixty-year-olds.

Dr. Cogan: What does VL stand for?

Dr. Blackwell: It is just how far above threshold something is. If I take a letter and dim it down so you can just barely see it, and then begin to increase it, that is the VL. You can see it happen and think it is more visible at a point, I keep increasing it but you do not see it any better. So VL has no more practical consequence. But a VL of two means that, if I were to flash that at you and you were looking right at it, you would just barely see it all the time. A VL of three means that you have fifty percent more contrast than that and you always see it, and you say, "I see it perfectly clearly, Doctor, what's the problem?" With a VL of eight, which is the current lighting standard in effect, if you look right at something, it is perfectly obvious. And that is why people say, "Well, why do we need all this light? I can see it." Well, you have to give them a realistic task involving certain scanning to find out whether they need it because they do not need it when the eye is fixed. Static viewing is a very simple thing.

Let me try to persuade you that the CIE report will be very useful to you. The most important aspect of this report we have not talked about at all, which is that it gives us an arithmetic for evaluating a real environment in terms of visual parameters of performance. Now, what are these?

First, if I want to rate this environment in terms of a number, a visual index of merit, how do I do it? I bring in my big machine with a computer on the tail end so I can do it fast. The first thing I measure is the physical luminance of a task. An ordinary telephotometer is all I need. But what consequence does that have, visually speaking? I turned to the standard visibility reference function in terms of a logarithmic scale upside down, which says, as the luminance of this task goes up, the relevant contrast sensitivity (RCS) of the eye goes up. However, it goes up very little, especially when one gets to levels of lighting to the order of thirty to fifty footcandles.

This function is just the reverse of the threshold we had yesterday. This way, it works the way you think it should. You do a little bit better when you have more luminance, all other things being constant.

Now, the way the thing actually works numerically is as follows: you look into a table in this report; you find out how many footlamberts you have, or candelas per square meter and you look up a number, an arbitrary number. Let me give you a couple, for example. Suppose we talk about an environment which had a hundred footcandles (I have already done this example—oh, shoot, I hate to test my arithmetic on the floor). A hundred footcandles is eighty footlamberts which is about 250 candelas per square meter. This gives you an RCS, arbitrary number system of about 70.7, which happens to be seventy percent of the best you could do if you had all the light in the world under ideal conditions. All right, now, suppose that I cut the light level in half. So I go down from my 250 to 125; that number drops from 70 to 64.2. That is a linear number and that is the right one from the eyes' point of view, which means that we only lost about ten percent of visual sensitivity by cutting the light level in half. It is very nonlinear, as you can see. The fact that those numbers change so little is a reflection of the fact the eye does not really care very much about how much luminance there is. The eye has an enormous range of response, over ten or twelve log units. So it is not surprising that there is not much change over three-tenths of a log unit in luminance.

Now, the next thing one must do, if one does this precisely as one does in a university, is to determine the extent to which the lighting geometry (it has nothing to do with the amount of light) favors a task. I cannot see a thing if the light source is improperly positioned and the task is shiny.

In other words, what we call the contrast rendering factor (CRF), that is, how much contrast is in the task as revealed under arbitrary sphere lighting conditions, which is a reference base line; is how much of that contrast is revealed by the lighting system. Now, in this particular room, there are places where the lighting is good and places where the lighting is bad. If you sit in a position where the luminaire is at a specular angle with respect to your line of sight, conditions are very bad. If you sit in between the luminaires, conditions are very good. This contrast rendering factor depends on where you are, the angle at which you look at tasks, the nature of the task, and many other variables that I will not bore you with by going into further. It is not only a physically measurable quantity, it is a physically computable quantity. DiLaura and I have published data which are being used around the country in a number of engineering consulting firms where they will compute, in an advanced installation, precisely what contrast there will be in a room all over the place, taking hundreds of positions and tabulating the contrast for ten dollars in computer fees. So it is a very efficient computer program.

Now, the CIE system says you take this RCS number for each of the two environments and you multiply by the CRF because the eye is a sensing device. If you increase the signal strength or increase the sensitivity of the machine to contrast, it is one and the same thing, so, these things can be multiplied. When you do that, you suddenly discover that the world is changed; and, indeed, many of our preconceptions about lighting are shot.

For example, one of the ones that I think is most interesting is, going back to the 1930's, Dr. Cogan, when people thought they knew what was good light, namely, indirect light. We discovered that, when we switched over from indirect lighting with low light levels to direct lighting with the new fluorescent tube and increased light levels by three times perhaps, we did not really change or improve vision at all. Although the light went up by three, the contrast, generally speaking, went down. Arithmetic shows you that. In many cases, you are worse off than before; and every architect in the business always thought this was true. But now science has finally caught up with common sense and we know why. It is because the eye cares linearly about contrast and non-linearly about the amount of light.

This is a fully developed technology and is described in the IES handbook.

Next week, at the IES National Conference, we will be talking about it right and left. This is standard stuff in terms of new buildings. In terms of old buildings, this measurement program that I have is absurd. It is not a practical thing to do except for a university professor.

Now, that is not all of it yet. There are two more pieces that belong in here that are most important. Not only does it matter what the contrast of a task is when you look at it and what the adaptation of the eye is to a much smaller extent; but also, it matters what the luminance ratios are in the environment, not just for comfort points of view as Dr. Fry discussed, but for two other visual performance reasons.

First, if I try to look at a blackboard with a window right beside it, there is a loss of contrast inside my eye due to entopic stray light which reduces the contrast of the image formed by my eye just as though I had reduced the object contrast. If I try to buy that back with more light, I have a very difficult time. I am working on a very flat curve and the tradeoff ratios are very unfavorable. In short, a small amount of disability glare, as we call it, is far worse than a large increase in light levels.

The disability glare factor (DGF) comes in to it in two ways in the CIE report. If you are looking at a task long enough to become adapted, as you might well be in a blackboard situation, the stray light actually improves your sensitivity a little bit at the same time it reduces the contrast of the image. Both of these can be taken into account in a straightforward manner. One can say, all right, I will multiply then, to get my index of merit, the RCS which tells me nearly what the adaptational sensitivity of the eye is at the luminance involved, times the CRF which is the physical measure of the contrast of the task, times the disability glare factor and, finally, we have a way to take account of transient adaptive effects. The eye never looks at an object fixedly; this is silly. The very nature of vision is that it must change; one looks around the environment. So one is constantly changing the adaptational state of the visual system.

Boynton and his student Rinalducci, under IERI sponsorship, have shown that you can explain this effect as a loss in contrast sensitivity and that you can compute it in advance on the basis of the ratios of luminances. Now, this is sort of what was all along behind the idea of limiting luminance ratios from a performance standpoint, which is quite a different matter from the discomfort standpoint that Dr. Fry talked about. But many of the same situations are bad in both regards. When you have bad discomfort glare, you are almost certain to have bad transient adaptation because the eye cannot resist looking at bright things that are not in the line of sight. The fixation reflex is well-known. Now, the system is to take RCS times CRF times DGF times the transient adaptation factor (TAF), and I will send you free copies of this booklet if you promise to read it! When you get through with this, you can then go back into the curve and express the visual significance of this environment in terms of effective illuminance, better effective luminance terms. In other words, I can say I start out in this room and the absolute luminance of my task is eighty footlamberts. I grind through all these calculations and these measurements and I say, yes, but the effective luminance of my task is twenty. That is the way it comes out. That is to say, where you have eighty footlamberts, the effective luminance is usually much, much lower in ordinary lighting situations.

In indirect lighting, it goes up. If I have ten footlamberts physically measured, I often have fifteen footlamberts in terms of effective luminance. So the whole method of evaluating lighting is monstrously changed by this thing which the IES has adopted. To be very careful, they have adopted only the first two terms in the equation, as far as I know, only because we have not fully developed practical ways to handle the others, and will not for months.

Dr. Halldane: When will that be coming? That has always been my bone of contention simply because there was no data which we could use to obtain an average that would be suitable from our point of view.

Dr. Blackwell: The nice thing about it, for application today, is that, if we are talking about interior environment and not roadways, and if we are talking about current methods of lighting which involve rather large sources, the *DGF* and *TAF* cancel each other out to such an extent that you really can ignore them both. One is greater than unity and the other is less than unity. When you multiply them together the product is essentially one. You can ignore the two terms as a shortcut engineering method. The reason is that our referencing system is arbitrary; it is a sphere. A sphere has two properties: diffuse illumination and uniform luminance from point to point. From the point of view of transient adaptation, anything that is not a sphere is worse than a sphere. So the transient adaptation factor is always less than one. But, from the standpoint of a stray light situation, a sphere is not the ideal at all. From that point of view alone, a very small field is the ideal. A sphere puts in seven percent of stray light. Looking down at a desk in a dark part of the room is better than being in a sphere. The number often comes out on the order of 1.03 which is three percent better than a sphere. Well, since so many of the transient adaptive effects are about three or four percent, you are multiplying 1.03 times .97 and you can, for all practical purposes, ignore it for the moment. For current engineering, the IES handbook says to use the first two terms and they call it equivalent sphere illumination (ESI). CIE calls it effective luminance or illuminance. It is the same thing although we consider effective luminance to be the preferred terminology.

Now, what does this do to environment and how could you do a practical job of applying this today? Suppose I convinced you that, for some reason or other, you want to have ESI standards instead of illuminance standards and that you would pick fifty and thirty or a hundred and seventy or whatever the numbers are. Is this something that could actually be done? Let me say that the IES thinks that it can be done for new spaces, because it is in their standard procedure. Let me say that my colleague DiLaura, who comes down from his company and spends months of his life with me, has developed a computer program which is so inexpensive that there is no excuse for not doing this for new buildings.

Dr. Halldane: I am worried about this very point. You are never going to convince an architect to use it if he can not translate that into an intuitive sense of what is going on. The crucial point happens to be the veiling luminance of a diffused surface and this happens to be your equivalent. Your spherical system is *nearly* the *worst condition for lighting* as it includes the direct specular component. The value is best when it exceeds unity. A designer simply does not have to have such a complicated measure to tell him not to have reflected, veiling light over his task. Your measure encourages a complete diffusion of light which makes spaces appear flat because of the absence of shadows to articulate form and to provide depth cues.

Dr. Blackwell: Well, now, wait a minute. Since I really want to get finished with this, let me say it this way. Education, perhaps, we should talk about later. Let me explain the system and say that architects have to deal with many things in engineering that they do not really understand. If someone gave them a criterion of fifty, they might only ask the engineer, "Tell me the cheapest way to get fifty." And that might be quite sufficient, especially if they discovered that, when this happens, they liked the environments they created. But, if they looked into the catalog and asked, "What about an indirect lighting system like Mr. Landsaw's? How will that do?" The answer is that it does remarkably well for low levels of ESI because it does have good CRF factors.

Now, I am trying to say that the exact engineering technology does exist. In addition to Mr. DiLaura, there are four other people around the country who can do it, all reputable engineering people. And so you could, as far as new spaces are concerned, use ESI engineering. As far as old spaces are concerned, you obviously cannot. My machine is not duplicable. There is no quick and dirty way to do this. The IES members have tried to find a quick and dirty meter; it simply is not possible. What can you do? Well, again, as a short-cut engineering device for checking on conformity to a standard today, DiLaura, or some other programmer, could put together what I would call an encyclopedia and show you the kind of ESI values you get per illumination unit. So you can take and get a ratio called the lighting effectiveness factor (LEF). This is the ratio of the ESI divided by the raw footcandles. Now, in a room like this, it will run around fifteen percent. That means eighty-five percent of the light is wasted, if you want to put it that way. That is the hard fact.

Now, the principles governing this can be made very complicated or remarkably simple. In a crude way, the smaller the area of the ceiling covered with light, the lower the LEF is. In other words, the old idea of indirect lighting or large area sources is really right. What is more, it comes through loud and clear in this ESI system. Large coffered wells have won all the competition to date, I believe. Maybe I am wrong, but let us say that direction of using large area sources does very well from a lighting effectiveness point of view. Now, of course, the way I am proposing this be done is that you give full credit to the efficiency of the use of a light source to provide illumination. This is all in the IES handbook. You can measure raw footcandles with a cosine-corrected, photopic illumination meter and then go into the encyclopedia and find a layout of lighting fixtures that matches rather closely the one you are concerned with. There might have to be twenty-five pages in the encyclopedia; there might have to be only ten or maybe a hundred, but this could be done by computer. This could be worked out on a standard basis. Now, each would have an attached LEF or lighting effectiveness factor.

A practical system, then, could be one in which you measure the raw footcandles in the usual way, find the picture in the back of the book that is the most likely room you have— and a green shirt can do that, in my opinion— and multiply the one by the other and see if the number is fifty or not, or whatever the criterion value is. I maintain that is practical today and the least you can do, in the next stage of your standards, is to get rid of an obsolete, meaningless unit which is illumination. And this is a practical way to do it, leaving the measurement still at the level of an ordinary footcandle meter, but giving the people the factor which will show them quickly that what has been considered good lighting systems because they put out lots of energy are, in fact, miserably wasteful. Now, I like the use of that word. If you are getting an LEF of fifteen, I call that wasteful. You have wasted eighty-five percent of the footcandles in non-visual benefits. Many lighting systems have

LEF's as low as fifteen percent. That would be a way to handle the problem of conformity.

What about the standard? What should you set as the standard for effective illuminance? All the data we have in visual performance were obtained under sphere conditions. Researchers in laboratories always do this because they do not want adaptive effects to contaminate their experiments. So, in fact, this is why we standardize on this arbitrary sphere. That is how all the experiments have been done. Strictly speaking, everything I have shown you is in terms of these units of effective luminance. So it is easy to go right into those data, then, without having to do anything else.

Now, depending upon the task, and how much searching and scanning you have to do, different amounts of light are required. Depending upon the criticalness of errors, different amounts of light are required. If an error is death, that is different than if an error is one percentage point loss in production. And, finally, individuals differ enormously one from the next. Now, at that point, what do you do? I am sorry there is not a peak function. All I can say is that it does not seem to work that way. You have to make an arbitrary decision. Now, where has the decision been made? Well, one can argue that you have already established that you are going to save some light because you feel convinced, perhaps, from the lack of complaints, that this is an area where something can be done. I want you to realize that information obtained from a twenty to thirty-year-old is not necessarily valid general information.

I find my students in the twenty- to thirty-year-old range do not understand why I care about light at all because they do not really much care about how much light they have. Well, I care because I am fifty-three. My point is that, if the decision-makers are young, we are in for trouble, because they do not understand my problem, which is that I am fifty and do not see very well. And what is more, I am not alone. That is the way the population of fifty-year-olds are.

So, once you know the facts then, how much light you need depends on what you are trying to see, whether it is black and white print or dim, archival material from the Library of Congress, how fast you have to work, how much scanning you have to do, who you are. Things begin to fall in line. Now, I do not know what is practical. I would like to see a graded system rather than a fixed system. To me, setting a fixed number is not the point. I do not like setting a fixed number, because, to me, that does not make sense. There should be a graded system and I think we know enough today to make a graded system. Within two weeks, I will send all of you, or anyone who wants it, the outcome of our latest experiment which has gone through my CIE committee. I have been told to go ahead, to charge ahead, and use them. These would give you a way to see, in detail, how you might want to grade lighting if you wanted to go into that degree of complexity.

It is almost as though you might say there are five grades of tasks, five grades of difficulty, in having to observe. Let us say you then look at the population distribution and decide what you are going to do to satisfy seventy-five percent. I think I can rather quickly put together numbers to show you what would be the outcome of different decisions along these lines.

One obvious decision is that you really should not lump all age groups together. You see, Dr. Weale's result and ours, which came from totally different directions, arrived at essentially the same answer, as did the early work of other people. We are purists, you know. We think the right answer should be exactly right, maybe that is foolishness on our part. The answer is, if you are over forty-five, light is a lot more critical than if you are under forty-five. Now, I just do not know how many different standards there could be. In our university, I am trying to work out a graded system so the university can use its energy budget in the most intelligent way to put the light where it is needed. I do not necessarily mean localized lighting, although that is not really for me to say. The engineers' problem is this: if someone decided in our lighting budget that we wanted to light the laboratories, where there might be explosions, higher than the classroom, where the kids are looking at the professor and doodling (which as you know is usually the case), how much light do you need to look at a professor and doodle? Well, very little! Most professors look better without the warts showing. And, generally speaking, their light is the wrong kind anyhow because their vertical surface is not horizontal. How much visual work do my students do when they take notes? From what I see, they do not do very much. They depend on the textbook. So, as has been said so many times, if energy is tight let us use a selective system.

Now, I think we can give you a basis for doing that; not an ideal basis, but an awful lot better than a meat axe technique of cutting the light everywhere in half. I would like to say we can give you a system where you can determine the consequences of any decision you make. I know that DiLaura has a computer program which has exactly that purpose, to tell you the consequences of any decision you might make in terms of performance data alone. You may find many things to do which had not occurred to you.

That is probably enough to say. I would like heckling and questions, if there is any time left. I think we have the far better information today than we have ever had before. It is good enough to be used for this purpose, and it should be used.

Mr. Crouch: I am not in disagreement with Dr. Blackwell but I am a little more cautious. May I say that, in my presentation yesterday, I presented all the facts as far as the IERI has them. Now, we have been waiting. Yesterday, Mrs. Blackwell as one of our researchers, presented the results on one hundred fifty-six observers under static viewing, looking fixedly at the spot of light, the signal. We have said, "This is wonderful, we like that very much. It shows what happens under every ten-year interval of age." But we also said, "This is fixed viewing and this is not life. Life is scanning." So we have been waiting and wanting and we are very happy with the progress that is being made of finding out what happens under the dynamic situation.

Dr. Blackwell: We just finished an experiment involving a population of forty-eight observers, in the twenty to thirty-year age group, doing highly difficult dynamic tasks. We gave them five Landolt rings separated by a total of four degrees and provided one-half second to see them all. Now, you know that is silly; they can not do it. We also gave them three-quarters of a second ane one second. All are extremely demanding visual search tasks. The question is to what extent did the variation in the dynamic performance of these observers follow their static threshold? Well, let us say that about eight-five percent of the variation was due to their static threshold. In other words, if we looked at the raw data, the spread of raw data on the different observers on a performance task was that great. When we expressed their conditions in terms of their own threshold, it shrank down to a very, very small variation indeed.

We believe that this small variation is real. In addition to variations in their contrast sensitivity, people in a different age group also differ in their motility. This shows up in a variation in the dynamic data after you have corrected for their sensitivity. But, again, for engineering purposes we know enough to tell you something. We can say that the dynamic performance will vary more than the static performance. We already have enough older observers to say that. So, again, it is the question of the timeliness of information. We are going to be spending another year trying to tie this together completely for the CIE. But, if you want a progress report, for what good it does you, I will be pleased to send you one because I think you will see that this is a lot better than nothing. Again, it is a conservative matter to use the data my wife presented yesterday. When dynamic conditions are involved, people vary more than that, not less.

Mr. Caplan: I was going to compare that to a situation that many of you may have been involved with, recognition training of aircraft shots going in and out of focus at a tenth of a second, and so on. One of the major differences that I found was the knowledge an individual had of the particular task. In other words, I had a guy in my class who knew everything about aircraft. He knew how big they were, their wing span, the weight of them, and so on. Even out of focus he could still pick those out at a twenty-fifth of a second; and when I would see them on there for a second, I still would not be able to identify them, because I was not familiar with them.

Dr. Blackwell: This is not a big problem in a simple thing like these broken rings. There is not a lot of information in a little ring with a break in it, the international test object for acuity.

Mr. Caplan: But, in a work activity in the real world, different people will bring different knowledge to that experience.

Dr. Blackwell: We find this out when people do dynamic experiments or do other so-called realistic tasks. It is true, as in Mr. Gallagher's experiments, that if you go into the field and do experiments, they vary from one another more than we say. But we know the direction of the discrepancy. If we take the contrast sensitivity data only, we are making a very conservative estimate of individual differences. It is the best we can do today and it tells you a great deal that I think is important. The twenty- to thirty-year-old observer has so much light he does not feel he needs it all. Then, talk to somebody older; you might get a different story. So, I agree with you, of course; but, again, we know we are being conservative in terms of variability.

We will give you a better answer next year and a definitive one the year after that when we hope to have an internationally standardized report.

Mr. Crouch: From experience, our distinguished committee under Dr. Fry has discovered some weaknesses which will allow for a better refinement of the final material that is available to the public. This eight (VL 8) that is involved was not originally an eight. We just arrived at a conclusion from experiments involving young, normal adults and the displacement above the fifty percent threshold. This eight is going to be strongly influenced by the dynamic results of experiments involving the rest of the population. So IES and IERI are not changing their position on the standard curve until they see what happens in the dynamic situation for the rest of the population. We obtained data for twenty- to thirty-year-olds in January and February of this year. I have seen the preliminary results, but as yet, there has been no submittal to IERI.

Now, may I say, that as I understand it, the CIE committee approved, not the material in the report, but an approach to go ahead with this whole thing.

Dr. Blackwell: The CIE committee gave me strict instructions to push ahead, not only in approach but in detail, to something practical and not wait any longer.

Mr. Crouch: We are thoroughly in favor of this. This was of course developed under the auspices of IERI and has been thoroughly gone over. We are thoroughly in agreement that we should not be talking about raw footcandles any more, but should be talking about effective footcandles. May I add that IERI has developed a new concept called effective lumens per watt. This new concept has been applied to all lighting systems including direct lighting, lighting involving both narrow and wide distributions, direct-indirect, and indirect lighting. Further, it has proved rather remarkable that, for good lighting systems, it varies all the way from ten or less to over forty effective lumens per watt. Therefore, we strongly advocate, in the viewpoint of conservation, that we not look in the catalog in that sense, philosophically, for poor lighting systems and see when you get fifteen percent. We would advocate that you apply a criterion developed by IERI of effective lumens per watt and limit the systems to those with wider distributions.

I would also like to say that there are types of direct lighting systems available which are far more effective than some indirect lighting systems. This is accomplished by changing the distribution of the troffers and already we have practical equipment that will do this. If you widen the distribution you can get thirty effective lumens per watt very easily, instead of the ten to twenty that you are getting from the light in this room. From a practical viewpoint, this is the way IERI would like to recommend that you go in the true conservation of effective seeing and wattage.

Dr. Blackwell: I guess all we disagree on is the matter of the criterion value and we do not have the final data. We agree fully on the rest of it which is that it is effective illuminance that you want to use. I am no man to tell you how to do it practically; Mr. Crouch is far better. And whether you use one of these methods or another is of no importance to me. The thing is to get rid of raw footcandles as a criterion because we know that it is meaningless.

Dr. Yonemura: Mr. Crouch brought this up a little bit in the sense that he said, we have to wait for data from experiments. You have been using so-called real-world tasks, real-world performance, Dr. Blackwell. Now, can you fill us in, in a general way, what the validation is from this to real-world tasks? What validation data do you have?

Dr. Blackwell: In a sense, we do not use real-world tasks. It is simplified and idealized and that is always the case. There are no real exceptions to that; and I am glad that Dr. Yonemura would still call these real-world tasks. In the CIE report, there is a summary of the knowledge that existed in 1971 of the relationship between visibility level and performance in real-world tasks. It is a curve, kind of a hodgepodge curve, but it shows you some interesting things. It does not use the data of Blackwell-Smith which Mr. Crouch used to define the ninety-nine percent accuracy level. That data, because of serious limitations, were withdrawn from the report.

We used the data of Weston, Bodmann, Boynton and Boss and Scott-Blackwell, an earlier form of the five-ring test. Now, to give a really short answer, let me say that a VL of eight corresponds to about eighty-four percent of the maximum performance. In other words, the idea that may have been promulgated about the IES lighting levels giving ninety-nine percent accuracy for tasks is actually not right. And I can tell you why it is wrong. That wheel task we did is not at all typical. It is too easy for two reasons. Each one of those little plaques always had the target in the exact center. Secondly, only about five of those plaques had targets. In other words, forty-six plaques had nothing, so the observer, in fact, only had six targets to look for. In that sense, there were never two of them in the field of view at the same time. At any rate, taking other people's data, which, in my opinion, are far more realistic than our data, we find, surprisingly enough, that we do not give anything like ninety-nine percent accuracy in performance with VL 8. On the average, we give no more than eighty-four percent accuracy.

Now, as a refinement we know that the performance at VL 8 depends critically on how much search you have to do. Our latest data shows the exact variation in this, expressed in terms of the degrees of searching required per second. In a shotgun way, we are saying that present lighting levels do not give one hundred percent performance accuracy. They give about eighty-four percent of the maximum you can obtain using twenty- to thirty-year-old observers. Values for the population as a whole drop considerably below that because all the early work that was done in everybody's laboratories, was done on twenty- to thirty-year-old observers.

So we had no great body of dynamic data on older observers. We have some now, of course, but it is not complete. It shows that the older observers do even less well than you would expect from their contrast sensitivity loss because of a motility loss. It makes perfect sense.

We had one wonderful seventy-five-year-old observer who gave us two weeks of her life. She was the kind of person whose intelligence was insulted if she did less well than a twenty- to thirty-year-old. She just simply beat herself to death to try to keep up with her daughter who was also observing, and there was no way she could do it.

The answer then is that a VL 8 does not provide ninety-nine percent accuracy in any realistic world task. Only in Blackwell's wheel was it provided, which was, in a sense, an unrealistic task, much more so than any of the others. I do not talk about that experiment any more; I repress it. Further, it was not put in the CIE report because it was not considered a good experiment.

Dr. Weale: In a paper published in the proceedings of—I forget which congress—ergophthalmology, I think, in the late sixties, there appeared a report on an analysis of the effect of refractive defects in a working population. This was a real-life situation.

Dr. Blackwell: Was it Sherfer's work?

Dr. Weale: I think it was Schmidtke and Schmale. The population was divided into four groups and an attempt was made to correlate the degree of ametropia with work performance. The contribution which ametropia made, between the worst and the best, amounted to no more than ten percent. In other words, good vision, admittedly not due to poor illumination played a relatively moderate role; it obviously involved a defect contrastwise because the retinal image was inferior. It was reduced contrast which was not due to inferior illumination. I think that from the optical point of view this makes very little difference. It was a tolerable difference and not a question of twenty percent. But, it is the sort of thing that people are prepared to put up with when they can not be bothered to go to see the doctor. Such difference amounted to no more than ten percent of the performance. It is the only quantitative set of data that I can quote.

Dr. Blackwell: I can confirm your result in another experiment in the little blue book. We can, in a laboratory experiment, study only sensory effects. We have our observers who are either paid or forced to participate by being students in a course. Presumably, they have gone through the routine before and they really try on these experiments. Now, the question is, if you find that illumination or refractive error makes a large difference in performance in a laboratory, what about in real life when other factors like intelligence, motivation, heat, family troubles and the like come into play? This is a very real consideration.

There are two philosophies you could take, and let me not choose between them. You can say that if in real life, variables other than visual affect the performance more, then, to that extent, visual performance is not important. That is one philosophy that one could take. I would accept that to a considerable extent. The other philosophy is that, because illumination can only improve vision, it can not presumably, help motivation much. Then you want to know what the visual effect is, realizing that in interpreting it, there is a sort of washing out.

We have here a real-life situation which gives the same result. There is an experiment by Mr. Gallagher, mentioned earlier today, in which he put cones in a real roadway where drivers on their way to the supermarket did not realize they were subjects. They were driving on a piece of highway under his control without their knowledge. He placed in the roadway, as obstacles, little cones which had a known visibility. He then changed the lighting on a month-by-month basis to provide different amounts of visibility. The experiments were conducted at night, and at some point the observers either saw or did not see a cone marker that was in the lane ahead of them. If they did not see it, they hit it; and if they hit it, they brushed it aside and nobody was killed. Most of the time people saw them and reacted. They reacted either by changing lanes to avoid the obstacle or putting on their brakes. The speed of the vehicles was electronically recorded as was the point at which they made a response.

Okay, what is the point of all this? Well, he showed that in this situation, using forty observers who did not know they were observers, as the visibility level increased, there was definitely an increase in the distance between the target and the point at which the observer took action. Fine. But what about individual differences among these people? He worked that out and he showed that there were very large differences among the different people. There were five different lighting conditions, in a sense, and so he had about two hundred people of unknown age in each of these categories. We assume that they were a random population of U.S. drivers between twenty and seventy years of age. The point is we know how much variability to be expected in their performance other than visually. And the answer was, in this particular case, that vision accounted for at least thirty percent of the total variability among observers.

My point is that we will always, when we can, obtain data to illustrate that the visual component which we control in the laboratory is only a part of human performance. Someone else has to determine what that means to them—whether they downgrade the importance of lighting for that reason, or whether they just understand that when you change lighting you change vision and when you change vision, you change only one part of performance.

There are other data which show exactly the same thing. It is interesting to see to what extent we can get data under different conditions and estimate this fraction. Gallagher's figure was a little higher than that mentioned by Dr. Weale, probably because driving is a pretty visual thing.

Mr. Caplan: Was he pretty well assured that the population was a similar type of population in all phases of the experiment?

Dr Blackwell: He had no real way of knowing. Let us say he randomized for different lighting conditions so that, if there were seasonal variations, it would not contaminate the results.

Mr. Caplan: Obviously darkness occurs at different times of the day in different seasons. In the summertime it does not get dark until nine or ten o'clock. If he did this at, say, five or six o'clock in the wintertime when people were going home, he might have a different population with different personal situations.

Dr. Blackwell: True, so what he did was randomize the different lighting conditions, changing them enough times back and forth that this kind of seasonal variable should not have affected the relative numbers under the different categories.

The meeting adjourned for lunch at this point, and the following discussion represents the final session of the symposium.

Chairman Heins: Hopefully, we can wrap up this meeting in about forty-five minutes. But, first I would like to review the basic objectives with you, then I am going to give everyone an opportunity to make final comments or raise any additional questions. The primary objectives, as I stated in my original letter to you and as I restated yesterday in my introduction, are to ascertain the current state-of-the-art knowledge regarding safety and health effects associated with reduced levels of illumination, to identify areas where research is needed and to create an awareness of these areas so that future research efforts might be appropriately directed. If anybody has any different ideas or suggestions regarding proposed research it would be particularly appropriate and appreciated if they would present them at this time.

Dr. Mead: One thing occurred to me earlier as Dr. Grimaldi was talking. He said there were maybe eight or nine percent of businesses in this country where the illumination was still terrible. I was just wondering whether they would not be good research sites to get a good measure of what the accident rate is in these places. Do they have any employee or foreman ratings of productivity? Are the jobs comparable to jobs being done in other places where the illumination is more desirable?

We are all agreed that we probably could not agree as to what "low illumination" really was or how "low" we ought to go. These might be working sites. I do not think anyone is going to be able to go into a new factory and lower the illumination to the levels you have described. But if they exist, conceivably, that is a kind of before-and-after thing we could work out. In conducting studies along these lines, we could bring in the medical doctors and the ophthalmologists and examine some employees to determine if there is a greater incidence of sequelae and symptoms of dysfunction. Without changing anything simply go in and see if this kind of situation is replicated elsewhere at higher illumination. Are there differences of the kind that we are interested in, such as safety, health, eyestrain, dysfunction and so on? However, all of us keep saying that we would rather talk about performance.

Dr. Grimaldi: This is a very good suggestion. There are a number of things that could be found out. It is not just the accident rate that we are interested in. We can talk about any of the exposures that might be responsible for the rate going up or down. We are also concerned about the environment itself. We might have, for example, a plant that has relatively good control over the kinds of hazards that are inherent in the operation and, at the same time, might have poor illumination. A plant such as this would have a much better record, therefore, than a plant which has poor illumination and a very poor control over the operation process. Simultaneously, there are probably some differences in the likelihood that the OSHA standards are going to reduce injuries, as opposed to those things that are not yet in the OSHA standard and maybe never will be, but may have a very strong bearing on the injury incidence rate. A study of this kind could develop, therefore, three sets of data.

Dr. Mead: Conceivably, these places might be the site for a whole new illumination change and then you would have another opportunity to see if you could relate performance to a change in lighting.

Dr. Halldane: The mine safety act went into effect three or four years ago and there have been a lot of political difficulties because in many cases the regulations were inoperable. For example, certain brakes were required on mine cars that could not be put into the vehicles. (I hope you people do not write standards that get into those sorts of difficulties; it is impossible to actually create the physical entities to achieve the control.) Now, when I set out the mine lighting standards they were based on a physiological response. The miner's nystagmus was the basic criterion I adopted. To avoid the nystagmus was basically to achieve photopic vision. And so, for those of you who are worried about safety and health and so on, you have to get over 0.05 footlamberts as the minimum. With brown coals of 1–7% reflection factor you need 5 footcandle illuminances to meet this.

Dr. Weale: The British criterion is double that.

Dr. Halldane: I know that. Things went out very well. I presented it at the American Mining Congress and the biggest headache was getting across the idea of luminance to the Bureau of Mines who never did get it. I have a fear the same thing is going to happen here. So, for goodness sake, listen to us on that, because I have had bitter experience with the task of trying to advise management groups as to setting up guidelines for standards of lighting that do not appreciate the subtleties in measurement nor the control of measuring devices, let alone what they represent. Therefore, they are likely to change it from your recommendations through the pressure of trying to get standards out in the minimum of time when you are not giving them time to do anything.

Chairman Heins: The objectives of this symposium do not include attempting to set regulatory standards on illumination.

Dr. Halldane: Well, whether they are standards or guidelines, I do not care. Sometime or other, a mandate usually comes through the Federal Register, or through GSA, or something like that. You have this problem with anything that goes through the Federal Register.

Mr. Pronk: I agree that we should avoid any attempt at establishing standards here. That was not the intent of GSA certainly. We are not a standard-making organization for nationwide policy. We do set regulations for federal facilities to follow and other people can choose to follow, if they so desire. But Dr. Halldane does have one valid point in that the information that comes out of here may very well be used by the people who do set standards. Again, we would like to caution that we give information to standard-making groups, such as the Occupational Safety and Health Administration in the Department of Labor, that can be applied in the practical world. That includes adequate measuring devices if we use different measuring terms. But I would like to concentrate on the health and safety aspects here and worry about the standards set by other people at a later date.

Mr. Crouch: In reference to the particular problem we are talking about here, I think maybe we ought to strategically limit our discussion to office buildings since the FEA and the GSA are largely thinking in terms of office buildings. We can get into great complexities in industry in that you can not get comparative situations, as far as machines and things of this kind, for a particular type of operation. But you can in offices. So I would suggest that maybe in Cincinnati—I am saying this with tongue in cheek—we could go to some of the offices that have these low levels of illumination in the GSA buildings, which I understand they do have, and examine the people to find out what their visual problems are.

Chairman Heins: What type of a study can you envision along these lines?

Mr. Crouch: Here in Cincinnati you have some beautifully lighted interiors for GSA buildings and you have some very poorly lighted ones. You could take a sample of a given size, making sure that the type of work is similar and deals with a certain quality of tasks. Then you could examine them ophthalmologically, as has been suggested, and see if there are more people suffering from visual defects in the poorer lighted interiors.

Dr. Blackwell: I think this is going to work. I think it is best to try the questionnaire approach and very carefully word your questions so that you are not suggesting them into complaining. You are not implying that you are looking for anything. You try to get something about the extent to which they find their work visually comfortable by never asking it exactly. I think it could be done, and I would expect that nothing you can measure in an ophthalmologist's office would give you these results.

Dr. Weale: We are not really concerned only with a person's vision. To put it as briefly as I can, only a fool would work under bad illuminating conditions. You may find that the offices where illumination conditions are poor and the factories where you have the very low lighting levels, attract people who can not find employment anywhere else. You have a self-selection process here and you are going to argue, if these lines are followed, on the basis of what is not representative, because you already have natural selection operating.

Mr. Crouch: Not in a Federal agency. They have to pass certain requirements.

Dr. Weale: I take your point; but, even then, they may be pushed or easily led or maybe there is somebody who is more or less resistant psychologically. It seems to me that this is something which should not be overlooked if this approach is going to be followed.

Dr. Halldane: I have a suggestion with regards to the interview or questionnaire approach mentioned by Dr. Blackwell. I put in a proposal to evaluate reflectors in luminaries. In one part of this particular proposal I stated that behavioral responses are difficult to ascertain because the changes in task performance anticipated from lighting changes are marginal. It is expected that responses involving a glariness or evenness of the luminaire (now we are talking about sticking in a reflector or modifying the light) will be observable. I suggested a psychophysical interview performed under the guise of a management OSHA survey a few weeks after each of at least two modifications to establish the cues people use so as not to make the person unduly aware of the luminaires. Now one of the biggest problems with any survey is to direct too much of their attention to the luminaires themselves. So it would be better to do a general survey to identify a whole lot of responses, whether it is a thermal, visual, or any other particular response. I am talking about a one-to-one interview technique. That is why I call it a psychophysical interview technique rather than a broad questionnaire. This way you can track down by an inquisitive inquiry, first of all, exactly what response cues that they are experiencing and, then, the specific stimuli that are inducing them. In this way, we can hope to correlate the responses with the specific physical entities. We can also find out those things which are unrelated to environmental issues because they will come up too. But there are quite a number of problems and I would encourage this type of survey technique rather than the traditional questionnaire or multiscaling things which are practically useless because they do not identify the response-stimulus parameters, and, therefore, can never become disciplines in design.

Mr. Hughes: Due to the time available I think the discussions should be limited to suggestions for areas of research rather than specific details.

Chairman Heins: I would like to present a couple of questions that we are facing as a result of the GSA's request. We have learned about ESI, about research that needs to be done and research that is in progress, the effects of age on the worker, and so forth. Right now, GSA has a practical problem. They have recommended or they have implemented reducing light levels from one hundred to fifty footcandles. Assuming that GSA will continue to implement this level, I have two questions: first, what magnitude of health effects are we going to experience, and, second, is it going to create any additional safety effect? In fact, do we have to worry about the safety aspects from a reduction of one hundred to fifty footcandles? Let us discuss the safety aspects first. Is there any safety effect or will we see any effect if illumination levels are reduced to the fifty-thirty-ten standard that the GSA is currently implementing.

Dr. Blackwell: That is a meaningless question on the basis of what was said this morning. We do say, by and large, when talking about safety in terms of not falling down the stairwell, chances are that there are no problems. On the other hand, without knowing in detail what goes on in the space, no one can answer the question. It is conceivable that there are things that some people cannot see adequately at fifty footcandles or, for that matter, at a hundred; so there could be a problem. It is certainly true, also, that the people at the end of the continuum with low sensitivity are affected quite a bit by a change in light. The people at the other end are not affected at all because they are either so far above threshold already or, even worse than that, they are way, way off the other end and it makes no difference in either case.

Dr. Halldane: Another area which I am very concerned about is the whole visual field and adaptation. What you are talking about specifically is horizontal illumination; and I contend that you should not reduce severely some of the ceiling luminances that we have, such as in hallways, because the ceiling becomes a very important cue for moving about in space. At the present moment, there are no recommendations in terms of ceilings and walls. The only thing you have is usually in terms of the reflectance of paint or something like that. Approximately eighty percent is recommended for a ceiling.

Now, my contention is, with dark floors, very restricted luminaires in our corridors, and cutoff angles that hardly illuminate the walls, we really have canyons of darkness. I think there should be some conscious effort to do something about illuminating the walls to increase the overall visibility of spaces. So my criticism is one of design and not one of the horizontal illumination or cutting down the amount of light. You can cut it down by half, but in doing so, if you take out your luminaires, a two-bank luminaire, you cut out almost half the distribution to the side walls if it is in a corridor. Now, you do not put ten footlamberts on a horizontal task. What do you have on the wall if you cut out half your luminaire distribution by cutting out a lamp? That is the practical issue that I am getting at and what I was referring to before as a consequence of making mandates without realizing the practical implications.

Chairman Heins: One of our main objectives was to define research topics or areas. Does anybody have any thoughts along those lines?

Dr. Fry: You are concerned here with a health problem. There are a couple of things I think which have come from this conference. At the outset, you had a statement from the Director of the National Eye Institute to the effect that the levels being recommended by the GSA would lead to no serious impairment of eyes or health. That has been verified by Dr. Cogan and I did not emphasize it in my presentation. I would like, at this point, to emphasize that although I talked about eyestrain, I tried not to make any claim. And, frankly, I do not believe that this could lead to any permanent or serious impairment of the health of the eyes.

Chairman Heins: That was one of my questions and I am glad you are talking about it now. Do you believe that eye fatigue, if repeated on a chronic basis, could lead to permanent irreversible eye damage?

Dr. Fry: I would make no claim that this is the case. You do not really know. There is an outside chance you might have some permanent impairment.

Chairman Heins: Do you know of any scientific evidence which suggests adverse effects associated with repeated eye fatigue?

Dr. Fry: You can develop things like sties, and this may lead to more complicated factors.

Chairman Heins: But on the other hand I do not believe that people should have to work under conditions which repeatedly result in significant eye fatigue symptoms.

Dr. Fry: You are talking about very low levels for this case. When you are talking about the recommended levels, and that is what we are talking about, you would not expect symptoms of eyestrain to be a source of difficulty.

Dr. Blackwell: I must take exception to that. We all agree, from a medical point of view, there is no dispute here at all that, in terms of the lay definition regarding damage to the eye, that there is none. We have all said that and said it again, so that can be completely confirmed without any dissenting voice. Now, I think we also all agree that it is not likely that operating under conditions that produce ineffective ocular motor adjustment functions and even headache, have any kind of permanent, irreversible effect on health.

You opened up the possibility that you will consider it to be a potential threat to health if a person has to work under conditions that make him repeatedly uncomfortable. Let us say every day he is uncomfortable. I do not agree with Dr. Fry's position that it is impossible that there could be this kind of health problem with the levels of light involved. If you believe the best information we have, there will be some people at the present lighting levels and more at reduced lighting levels, who will be operating sufficiently near their own threshold that inferential evidence, based admittedly on very little research, has suggested there might very well be eyestrain in Dr. Fry's sense. If that is true, we must not conclude, as Dr. Fry said, that these levels produce no threat to this definition of health because our evidence indicates that it is likely there are problems for some people.

I would almost turn it around and ask the question: "Have people complained of eyestrain?" I am told that they have. Personally, I did not know if I could believe them, realizing there are many bases for a person's imagining difficulties that are not real. I concluded that I could believe them. If the whole population told me this, I could not believe it. But, if ten percent of the population told me this and if it was concentrated in the older age groups, I would have to say that my experiments suggest it is believable—not proven, but believable.

I was asking before, what percent of complaints came from people in the older age groups. Again, this is not proven and, if you want to know more, additional research has to be done.

Dr. Cogan: I would like to return to the subject of chronic eye damage which may result in a permanent impairment of vision.

Mr. Crouch: I think Dr. Fry was saying—well, I should not be explaining what he was saying —but he was saying, if there was a bad enough condition continuously, permanent damage or impairment could not be ruled out.

Chairman Heins: He did not say definitely no. He did not think so or he does not know of any evidence to indicate it. However, it is possible.

Dr. Blackwell: There is no evidence, right. But, since you opened up the possibility that even if there were not, we would still consider it a possible health problem. We do not have to decide about that at this point. You state that you do not think it is right that a worker should have to go home chronically, frequently, with eyestrain or headaches.

Chairman Heins: That gets into another area like the psychological area.

Dr. Blackwell: Well, I do not believe it is psychological at all. I am relating to the problem.

Dr. Halldane: Have you evidence that this happens? That is the point.

Chairman Heins: I think it would be a well-established fact that, if people had to perform difficult tasks under very poor illumination levels, they would wind up with eye fatigue or eyestrain at the end of the day. The symptoms including headaches, etc., could lead to their being very unhappy individuals. Every time they go to work, they are going to go home with a headache.

Dr. Halldane: Do we have this information from a GSA survey as a consequence of the conservation effort?

Dr. Cogan: That is not in the range that you are interested in. You are interested in something way above that level of illumination, are you not?

Mr. Pronk: From the number of employees in the GSA facilities and the number of complaints we receive, we think it is quite low. We have only had about forty complaints from individuals who made the effort to write directly to the GSA. Now, how many people complained internally, we do not know. The supervisors did not follow through. We have had some union complaints. Now, the union complaints make it difficult to determine whether it is one employee or ten who complained. So we do not know, really, the number of complaints we are talking about. From the amount of opposition we got, we feel it must be a very small percentage of the total employee group. However, we want to make clear that we are concerned about the small percentage. The employee today wants to know, that is he considers he has a right to know, what is a good environment for him to work in, what is a healthy environment, and demands that he get it. It means, and I gather from what you have said, it is a very small group that requires a higher level of illumination. We want to provide this, but we do not want to provide it if ninety-eight percent of the other people do not need it.

Dr. Blackwell: What I am saying is that I think there is presumptive evidence that this could be a problem among your older workers and that you could do something about it.

Mr. Pronk: This is a variable we want to define if we possibly can. If not, further research is needed.

Dr. Yonemura: You are talking about a very small group that, probably for convenience, may complain about the light. They just do not like the boss; they do not like the job.

Dr. Blackwell: I understand that. We do not know today, but I think that on the basis of what we showed you yesterday, it is at least possible there could be some legitimate complaints among people in the older age group who have low sensitivity.

Dr. Cogan: I like low illumination and I am in the older age group.

Dr. Blackwell: There are two things I must insist on. First of all, individual differences are enormous and some seventy-year-olds are as good as many twenty-year-olds. My second remark is that I wish we would stop talking about low illumination and start talking about low visibility because low illumination does not provide any effect as such. It is doing something difficult under low illumination. Low illumination is not a visual parameter, low visibility is.

Dr. Cohen: I appreciate the fact that we seem to be going around and around with this definition of health. From time to time, the Public Health Service seems to subscribe to the World Health Organization's definition of health, which is not only absence of disease but a complete state of physical, mental, and social well-being. A person who goes home with a tired feeling owing to the concentrated visual effort he has made during the day, perhaps due to low levels of illumination, would be covered by this type of definition.

Dr. Blackwell: There ought to be some easy medical or optometric screening to verify whether or not people who complain about lighting have a legitimate complaint. We are developing a little gadget that could be computerized to use in making a quick, personal survey of all the responses to the variables of light. We are doing it because we want to survey. We have a battery of tests, including contrast sensitivity under static and dynamic conditions, glare sensitivity, transient adaptation sensitivity, discomfort glare, etc. In each case we measure the pertinent responses. We have been doing this since last year.

Now, the new one would have some kind of method of assessing performance at low visibility levels to see if there are legitimate physical evidences of ocular motor insufficiency. With such a battery, one could determine (we hope to do it in the university) whether some people are right in complaining about the lighting. This can be done, in my opinion, by the battery of tests. We have been doing all these things with laboratory-type equipment, but we can make three of them so we can do three people at the same time. If this works out in the future, it might prove useful in verifying (in plants, by medical referral to a big hospital area) that this person, indeed, has a legitimate complaint and should be given special supplementary lighting.

Dr. Halldane: Please do not say *all* responses because I can think of a lot of other responses by which we can evaluate an environment.

Dr. Blackwell: We are measuring only physiological complaints, nothing else.

Dr. Fry: Getting back to the research needed, we have talked about the sources of eyestrain. I came here prepared to talk about eyestrain and that type of thing which results from the adjustments the eyes have to make in performing a task. These same adjustments are also involved in performance. If you are interested in getting at the basic research with respect to both performance and discomfort, these adjustments, I think, need to be studied. That is, there are things you can get at quantitatively. You would be able to get a basis for determining at what levels these adjustments become important for discomfort and at what levels they become important for performance. It is my own feeling that the levels you are discussing are above the levels at which you are going to get the discomfort. But it is still important to study these mechanisms because they affect both discomfort and performance.

Dr. Cogan: We are influenced greatly, I think, in the levels of illumination selected by questionnaires that are sent out to people. People want levels much higher than the operative level of efficiency. Well, the reason they do is that they have the impression that it is healthy or that there is some health involvement. People think the more light you have the healthier it is for your eyes. That is the common popular opinion. When you ask people if they have enough light, they believe that they have to have a lot of light because it is healthful. The evidence for this belief, I think, is questionable. On the other hand, the evidence that excess light may be damaging the eyes is also questionable. But, I think the evidence that excess light is damaging the eyes is just as good as the evidence that insufficient light is damaging the eyes. If we can get across to the people that excess light may be damaging their eyes, I think they will object to having high levels of illumination. As soon as the public begins to think, it will be just like cancer and smoking. They will automatically ask for lower levels of illumination once they think it may be damaging their eyes. My suggestion is that you push the idea that, although the evidence is very questionable, we have not had a big survey like the smoking survey; there is still a possibility that excessive light is hurting your eyes. And I think people will automatically ask for less light. It will be a very simple solution to the whole energy problem, I think.

Chairman Heins: Most of the research to date has been done on young, normal eyes. Present research is being conducted on older, normal eyes. Is there any research currently being done or contemplated using abnormal eyes?

Dr. Blackwell: This is needed research, yes. We are hoping to get into this by persuading the university to let us take the entire population of a building as it comes without making any efforts to refract them. It would be a raw population of people supposedly intelligent enough and wealthy enough, university professors and students, to have had reasonable eye care.

Mrs. Blackwell: We do have data on very abnormal eyes, if you want to put in that category eyes which are precataract, have some kind of retinal degeneration, or extreme cases of that nature. So we know the direction which certain kinds of abnormalities are apt to take.

Dr. Blackwell: Since I have not made a suggestion for research, there is one I wish someone would work on. I mentioned personally several times to people, that being a presbyope of advanced state, I am awfully sensitive to the problem of depth of focus. I must say that I talked to Dr. Weale and he agrees with me that apparently no one has made a study of the special effect of light which has nothing to do with visual performance in the usual sense. It is concerned with the fact that, if you are not in focus at a given distance and cannot focus, you must depend upon light to pull the pupils down to give you depth of focus. We never study this because we deliberately always refract people for the distances of our targets. I should not have said it does not relate to performance, but we have never studied the question of depth of focus to see if there is a special effect of light for the presbyope which has simply not been added in.

Dr. Weale: I just read the result of some research which I was told about a long time ago. There were a couple of old ladies, I assure you this is true, who could not see very well but could not be bothered to wear glasses. When asked why, one of them said: "Why, look. We have these biscuits." The biscuits were perforated; and, whenever they wanted to read, they would put one of the biscuits in front of their eyes and were easily able to focus. And if Professor Blackwell has any difficulties—

Dr. Halldane: These can be purchased out of a "Sunset" catalogue for a few bucks.

Mr. Crouch: I would like to propose some research. I have been talking about other people's suggestions up to this point. But, I think, that in view of what I have learned at this meeting from Dr. Blackwell on the deterioration of vision for older people, I would suggest that we reinitiate under very carefully controlled conditions the measurement of fatigue and nervous muscular tension while doing a difficult job and an office task of poor contrast—the ones that we say require illumination levels—and measure the fatigue with young and old. It has never been done with old, as I recall; it has always been done with young people who tend to rise over the situation and overcome the difficulties. I suggest we reinitiate it under much better controlled conditions than in the past when we changed the levels of illumination and measured the nervous muscular tension.

Dr. Blackwell: I reinforce that by saying you see this problem historically on those experiments and so many others when we did not really know what the variables were. If someone did an experiment like Tinker's with a high contrast target and got no muscular tension, it is not surprising. We know today the target is so visible at low levels of lighting that there is no problem. So I would say that now we know enough to know how to measure suprathreshold visibility.

Dr. Cohen: It would be well to see if we could verify a point that Dr. Grimaldi made earlier today with regard to statistics in industry where visual problems or illumination problems seemed to be associated with accidents. I do not think we have good enough causal factor information with regard to industrial accidents yet. The twenty percent figure which was discussed earlier surprised me to a great extent. Could some selective investigations be undertaken to verify that figure?

Chairman Heins: Dr. Grimaldi mentioned that approximately twenty percent of the accidents were associated with poor illumination. However, if someone tripped on a chair and you asked why, the reply might be, "Well, I didn't see it." This does not necessarily mean that there was inadequate illumination. This raises the question of how meaningful is that twenty percent figure, Dr. Grimaldi?

Dr. Grimaldi: Five percent of the reported accidents were directly related to illumination. This is where they fell in a hole or something of that sort. Twenty percent were associated with illumination. This is where there was a claim of eye fatigue or some other problem that might be attributable to illumination. I think that this would be a very good area for study. I am sure that the Bureau of Employee Compensation has some pretty good data on what is taking place on Civil Servants.

Dr. Cohen: Would a records evaluation, or what we call a record study be useful?

Dr. Grimaldi: I do not know exactly the form in which the information is available. I suspect that it is not too good because all the data collected in this case are intended to assist the legal and insurance responsibilities that are a part of employee injuries. Nevertheless, there is something of value here. It may be useful, considering the large number of government employees involved, to look for example, at last year's data. A number of these employees are still, I am sure, with the government and we could do some historical investigation on the case that may be of some use. We might also get some more definitive information on how, exactly, the employees associated illumination with the injuries that they suffered. This would be much more than we have right now.

Dr. Cogan: There is a very practical chapter in Keyes Metcalf's book on libraries, chapter nine on lighting. In this chapter he wrestles with this problem of poor-visioned people who use libraries. It seems to be an example of just the sort of thing we have been talking about on levels of illumination. They have solved this in the library by having a special room for the visually handicapped (and professors) for lighting with general illumination. This is really a very practical solution to the same type of problem that we have.

Mr. Crouch: I am surprised, Mr. Chairman, that Dr. Blackwell has not suggested the possibility of carrying out further what he has already started, which is his trial, his first one observer, the visual dysfunction, the change of pattern of viewing which indicates a much more difficult—an increasing difficulty—as a person tries to do the job.

Dr. Blackwell: I thought Professor Fry had already said it. He said, the way I interpreted it, that not only did you want to know about the ocular motor basis of discomfort, but also that performance is affected by ocular motor functions. The two, in a sense, are related. I would like to see some kind of support for the idea that someone should do a systematic study of the ocular motor function in terms of suprathresholds disability with respect to lighting, and to study, in particular, older observers who have high thresholds and low sensitivity. And, one should go one step further, if possible, to collect symptomatic data at low suprathreshold factors when an observer is required to continue to do visual work for a longer period under these conditions. The ordinary lab experiment is not good enough. You would have to have an observer operate for two or three hours at a suprathreshold factor of four and occasionally probe the ocular motor system and record symptom.

Chairman Heins: I dislike bringing this discussion to an end but it is getting rather late and many of you have planes to catch. On behalf of the National Institute of Occupational Safety and Health I wish to thank all of you for participating in this symposium.

EPILOGUE

National Institute for Occupational Safety and Health

The necessity to conserve our Nation's precious energy resources has become increasingly apparent. Many current practices of energy use are being critically examined in hope of reversing, or at least dampening, the current trend of increasing energy demand. Installed lighting, according to Federal Energy Administration (FEA) estimates, accounts for approximately 5 percent of the Nation's total energy consumption and more than 20 percent of the electrical energy produced. Although lighting does not consume a major portion of our Nation's total energy, it does represent an area where conservation can be realized.

Consequently, the Federal government, as well as many private organizations, is implementing programs to conserve lighting energy. FEA, in cooperation with the General Services Administration (GSA), has initiated a policy for reducing the illumination levels in all Federal office space. The illuminance levels are now limited to 50 footcandles in the working area (on the desk top), 30 footcandles in the general office environment, and 10 footcandles in hallways, corridors and other seldom occupied areas (50/30/10 standard). Because the reduction in illumination levels has raised questions regarding possible adverse effects on worker health and safety, NIOSH was requested to make an initial evaluation of the potential problem. This symposium was sponsored by NIOSH as a forum for discussing these potential effects by a small group of selected experts concerned with the effects of working at reduced illumination levels. The specific objectives were:

1. To assess the current information about the effects of reduced illumination of consequence to worker safety and health.
2. To create an awareness of areas where research is needed so that future research efforts can be appropriately directed.

It became obvious during the symposium that the primary emphasis in the field of vision research traditionally has been directed toward the study of visual performance. With an abundant energy supply, the ability to see quickly and accurately was stressed. These considerations formed the basis for illumination criteria which were formulated into recommendations by the Illuminating Engineering Society (IES) and subsequently adopted as standards by the American National Standards Institute (ANSI A132.1–1973 for Office Lighting and ANSI A11.1–1973 for Industrial Lighting). Specific lighting requirements have also been incorporated into some sections of the Occupational Safety and Health Administration regulations. The limits adopted by FEA and GSA for office lighting are approximately one-half of the values recommended by IES and ANSI. Although the performance of an individual could be affected to some degree by this reduction in illumination, performance, apart from safety considerations, is beyond the scope of NIOSH's responsibility. Due consideration, however, is warranted by the experts most intimately involved in visual performance. Our discussion will be limited to safety and health considerations.

The illuminance levels recommended by IES and ANSI for safety alone range from 0.5 to 5.0 footcandles, depending on the level of activity and the degree of hazard presented to the worker. These levels represent the absolute minimum illumination for safety of personnel at any time and at any location on any plane where safety is related to seeing conditions. Interestingly enough, the GSA minimum lighting requirements are twice these values prescribed for safety alone (see Appendix A). Certain conditions or activities may require different levels of illumination. In addition to illuminance, there are many other less tangible factors associated with poor illumination which can be important contributing causes of accidents. These include direct and reflected glare, harsh shadows, excessive visual fatigue, delayed eye adaptation, individual differences due to age and refractive errors, and other physiological and psychological variables.

In discussing industrial accidents, Dr. Grimaldi stated that, according to National Safety Council (NSC) estimates, insufficient lighting is the sole cause in 5 percent and a contributory cause in 20 percent of the accidents. He further stated that these are estimates, based for the most part on reports provided to the NSC by its members, and are not corroborated by any good scientific information. Dr. Cohen pointed out that the 20 percent estimate may be only the tip of an iceberg because until recently accidents with no lost work time were not usually reported. Also, routine accident investigations are seldom thorough enough to ascertain whether illuminance or other factors affecting visibility at the time of the accident have, in fact, contributory significance.

Indeed, few studies have been deliberately undertaken to evaluate the role of lighting in accident occurrence. This was acknowledged by the symposium participants. Among the few studies noted, one showed a 32 percent decrease in accident frequency when the illumination was increased from 5 to 20 footcandles. A subsequent decrease of 11 percent resulted from repainting the work area to obtain a more favorable brightness ratio. Although this study was not carried out under well-controlled conditions, the reported decrease in accident frequency suggests a correlation between lighting conditions and accident occurrence. The need for verification of such correlations through further investigation is clearly indicated. Therefore, we suggest that detailed studies be implemented to determine the significance of illuminance and other contributory factors on accident potential for a cross-section of work situations.

Although the minimum lighting levels now implemented by GSA are above those recommended by IES and ANSI for safety alone, GSA nevertheless was concerned about the potential impact of reduced illumination on occupational safety. We concur with the general consensus of the symposium participants that, based on present knowledge, the 50/30/10 standard should not pose an additional hazard. In the implementation of this standard however, care must be taken to avoid problems associated with disability glare and widely varying light levels which can occur by removing portions of lighting systems not designed with this action in mind. We recommend that GSA consider initiating a system of accident reporting which will more clearly define possible relationships between lighting and accidents.

Another concern to both GSA and the worker is whether the reduction in illumination levels could result in permanent impairment of vision. The symposium participants agreed that low illumination will not result in any physiological or anatomical damage to the eye. Further, no scientific evidence was presented during the symposium to indicate that eye disease or permanent impairment of visual function will be caused by working at the GSA illuminance limits.

Headaches, "tired eyes", local eye irritation, and general fatigue are a few of the symptoms of asthenopia, commonly referred to as "eyestrain". Complaints of these symptoms are usually associated with an individual's efforts to adjust his eyes for proper seeing under inadequate lighting conditions. According to Dr. Blackwell, the origin of these maladies most likely lies within the oculomotor system, with discomfort possibly arising in the ocular muscles which operate these systems. Eye muscles, however, can also become fatigued and similar symptoms may occur during periods of extended use even under ideal lighting conditions. It is extremely difficult to verify compaints about insufficient lighting, as there is no easy screening device or method presently available which can be used to differentiate the symptomatology associated with asthenopia from that attributable to some other etiology. A few complaints will undoubtedly be received due to the mere act of reducing or "taking away" the lighting to which persons have become accustomed.

Although the subject of asthenopia stimulated much discussion, it was generally agreed that the repeated occurrence of this syndrome would probably not lead to any permanent effect on the eyes. We do believe, however, that the local irritation, headache, and fatigue produced are annoying and uncomfortable and should be avoided when possible. It was recognized during the symposium that persons with visual handicaps and persons in older age groups (over 45 years of age) are more likely to encounter symptoms of asthenopia than younger, normal-visioned persons because of the need for increased light under similar working conditions.

A number of areas in visual health research seem to be indicated from the discussions. Several of the symposium participants pointed out that the use of the quantities (units) illuminance (footcandles) and luminance (footlamberts) is not effective in specifying lighting requirements. Both the International Commission on Illumination (CIE) and the IES have been working towards the development of a system of effective luminance to account for several additional variables. As a result of this general trend away from measuring and specifying lighting levels simply in terms of illuminance to effective luminance, development of a method or instrumentation to evaluate effective luminance is essential both to safety and health research and to an energy conservation program. Such development should be encouraged and future research should employ this terminology.

The symptomatology associated with asthenopia is thought to result from the reduced efficiency of oculomotor adjustment functions. The mechanisms, however, have not been fully elucidated. A recognition of the determinants for the resulting symptoms is necessary, not only for the increased knowledge of the ocular motor system, but also for development of a means for separating valid complaints of asthenopia from those of other etiology. It would also be useful to study the occurrence of asthenopia as a function of visibility level. With this information, better estimates can be made of the percentage of the total working population which might suffer from asthenopia both at the present GSA illuminance levels and at any other levels which might be established in the future.

Although additional research is needed in several areas, there is not sufficient evidence to justify a recommendation countermanding the GSA illuminance limits on the basis of safety and health considerations. While it is impossible to accurately determine the extent and implications of this potential problem, it was generally agreed, and we concur, that only a relatively small percentage of the working population would be affected. This includes primarily persons in older age groups, persons performing demanding visual tasks, and persons with existing visual handicaps. For these individuals, we suggest that appropriate measures (e.g., supplementary lighting, use of lenses, use of daylight, increased task contrast, etc.) be taken so that the symptoms of asthenopia attributable to inadequate lighting will not repeatedly occur.

No attempt has been made in this discussion to summarize the individual presentations or to reiterate all the suggested research discussed by some of the participants in Appendix B, but rather to emphasize the salient points pertaining to safety and health. An abundance of useful information is contained within these proceedings and a comprehensive reading is recommended for persons interested in this subject.

We hope that this symposium has contributed substantially toward the knowledge and awareness of occupational safety and health issues related to reduced levels of illumination. Additional research in this area is certainly warranted.

APPENDIX A.—Lighting and Thermal Operations Guidelines Federal Energy Administration.

Lighting and Thermal Operations

Energy Management Action Program for Commercial•Public•Industrial Buildings

Guidelines

Federal Energy Administration
Office of Conservation and Environment
Washington D.C. 20461

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price $2.30

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TABLES

Foreword

Today's energy problems, which were intensified by the oil embargo to the U.S. in the winter of 1973-74, have developed from trends in the production and consumption of energy that have persisted for some time. Energy consumption grew at an average rate of about 3.5 percent per year from 1950 to 1965 and then increased to 4.5 percent annually. Domestic energy production grew at an annual rate of 3 percent between 1950 and 1970, but has been at a virtual standstill since then.

Essentially, then, the most basic energy problem we face is a growing gap between growth rates in production and supply. There are two approaches to closing this gap and meeting the Nation's energy needs: First, discovering and developing both new and traditional energy sources (increasing the supply) and, second, decreasing the rate of growth in the demand for energy.

Commercial, public, and industrial buildings, and the people and activities they house, represent the most rapidly increasing demand for energy. In response, the Office of Energy Conservation and Environment of the Federal Energy Administration is working with representatives of this sector to seek their voluntary cooperation in reducing energy consumption. Initially, this effort will address indoor lighting and temperatures and modes of building operation.

This publication contains guidelines which represent desirable targets with regard to illumination levels, efficiency in lighting, and operating heating and cooling systems. Many organizations have attained these levels successfully; others have adapted the targets suggested to meet their unique characteristics and needs. Broad cooperation with the principles of energy conservation represented by these guidelines will have a significant effect on decreasing energy demand and will make a vital contribution to assuring sufficient energy supplies in the future.

Roger W. Sant
Assistant Administrator for
Energy Conservation and Environment

Glossary

Balance temperature	The outdoor temperature at which the internal heat gain of a building (from lighting, people, and machines) equals the losses through walls, roof, and windows.
Ballast	A device used with gaseous discharge lamps and tubes to limit current flow and to provide voltage control at proper design levels.
Btu	British thermal unit, a unit of heat energy. Classically, the heat required to raise 1 pound of water 1°F.
Commercial space	Offices, schools, stores, administrative space, public space, hospitals and other health and laboratory space, and warehouses.
Contrast	The relationship between the luminances of an object and its immediate background.
Footcandles	A measure of illuminance produced on a surface all points of which are 1 foot from a directionally uniform point of 1 candela. That illuminance is 1 lumen/ft^2 or 1 footcandle.
Glare	The sensation produced by luminance within the visual field that is sufficiently greater than the luminance to which eyes are adapted to cause annoyance, discomfort, or loss in visual performance or ability.
Heat redistribution system	A system which transfers excess heat from one zone of a building to another zone which requires heat, as from the interior zone to the perimeter zone. This usually minimizes the total energy required for heating.
Industrial space	Space in buildings or other structures in which fabrication or other manufacturing is performed.
Interior zone	In a multistory building, the interior space beginning about 15 feet from the outside wall and including all floors except the top. This space is not affected by outside temperature.
Lamp	A generic term for a manmade source of light.
Luminaire	A complete lighting unit consisting of a lamp or lamps together with parts designed to distribute the light, position and protect the lamps, and connect the lamps to the power supply.
Lumen	A unit of luminous flux.
Nonuniform lighting	Task lighting only where needed within a space, in contrast to task lighting levels provided generally throughout the space.
Occupied hours	The time when a commercial, industrial, or institutional building is normally occupied by people functioning in their jobs.
Setback temperature (or night setback)	In the interest of economy and energy use, temperature in the winter may be set back to 60°F during the unoccupied hours instead of maintaining 68°F, as during occupied hours.
Static Luminaire	A conventional lighting fixture having no air flow (other than normal convection) through the lamp compartment.

Unoccupied hours	The time when a commercial, industrial, or institutional building is normally empty of people, except for a few attendants or maintenance personnel.
Veiling reflections	A reduction in task contrast due to light rays which are reflected specularly from the surface of tasks rather than absorbed and reradiated diffusely in the observer's eye.
Watt	A unit of electric power or heat power. 1 watt equals 3.4 Btu/hr.
Work area	Circulation area within work space but not at work station.
Work station	Space (such as a desk top) where task is actually being performed.

Lighting & Thermal Operations Guidelines

ENERGY MANAGEMENT ACTION PROGRAM

LIGHTING

Background

Total energy consumption for direct lighting in the United States in 1972 was slightly over 20 percent of the total electricity generated for all uses. This percentage amounts to

360 billion kWh (kilowatthours)
or 3.6 quadrillion Btu's (British thermal units)
or 1.7 million barrels of oil per day
or 5 percent of the total national energy consumed.

Estimates of possible energy savings by implementing energy conservation measures are as high as 43 percent of lighting usage, or about 2 percent of the total energy consumption nationwide.

Because energy for lighting consumes an especially large fraction of electricity and because recent trends in lighting contribute to increased electricity consumption, the Federal Energy Administration is releasing these guidelines for indoor commercial and industrial lighting to encourage efficient lighting practices. The fact that virtually all artificial light is produced by electricity makes efficient lighting practices especially important in alleviating a number of national problems, which include: (a) present and future projected shortages of energy resources generally, (b) special difficulties in providing for increased electricity generating capacity, and (c) problems of additional peak electricity demands created by air-conditioning equipment which must remove waste heat from lighting systems.

Commercial, public, and industrial buildings account for approximately 70 percent of total lighting energy consumption. Energy conservation measures affecting lighting practices in these buildings are therefore likely to be especially important to progress toward goals of energy reduction. Recent lighting design practices have favored higher and higher levels of illumination and have seldom taken full advantage of energy saving opportunities principally because the formerly abundant, economical supply of electricity and fuel provided little incentive to conserve energy.

Energy conservation in lighting systems design and operation

Design, installation, and operation of effective lighting systems have complex scientific, management, engineering, and architectural components. Of the many elements that must be considered in providing an adequate visual environment at acceptable cost, energy conservation is only one, but recent events and future prospects for the demand and supply of energy have underscored the necessity of giving conservation greater weight. Other elements that must be taken into account are the visual tasks to be performed, the physiological state of the observer's eyes, the psychological state and perceptual skill of the observer, the design of task and surrounding areas, the availability of daylight, the level of illumination, and the lighting system quality with regard to spectral characteristics, glare, veiling reflections, and geometrical factors.

These complexities limit the degree to which simple guidelines for energy conservation in lighting can be applied in all cases. However, in most situations they are very useful in providing the guidance necessary to achieve substantial savings in lighting energy and cost while also providing an adequate visual environment.

Variations in visual requirements for different tasks for different observers and other considerations are responsible for some situations where additional analysis is needed. The objective of the guidelines is to provide useful assistance in the design and operation of lighting systems to minimize energy consumption, including direct and indirect effects. There are some situations where measures beyond those specified in the guidelines may result in additional energy savings. The expert assistance of architects and lighting engineers can provide additional guidance.

Illumination levels guidelines

The following illumination levels are recommended as desirable target levels for modifications to existing systems or for design of new ones, under the condition that energy savings are thereby effected. See Tables 1 and 2 and Glossary for details.

Commercial buildings

Office buildings, administrative spaces, retail establishments, schools, and warehouses. During working hours, illumination levels should be reduced to 50 footcandles at occupied work stations, 30 footcandles in work areas, and less than 10 footcandles in areas that are seldom occupied or which have minimal visual requirements such as hallways and corridors. Where needed, because of exceptional individual requirements or because of the difficult nature of a specific task, nonuniform supplemental lighting may be provided for the task duration not to exceed levels indicated in Tables 1 and 2. Individual switches should be provided to permit maximum control over both standard and supplemental lighting when not needed. Lights should be switched off whenever daylight can be used.

Industrial buildings

Factories and plants. For industrial lighting, levels at the work station should be no greater than those recommended by American National Standards Institute Practice for Industrial Lighting A11.1-1973 (June 1973), no greater than 30 footcandles in work areas, and no greater than 10 footcandles in nonworking areas, except in a few special cases specified by the Occupational Safety and Health Administration. Daylight, when available, and switching should be used to the greatest degree possible to reduce energy consumption.

Hospitals

Illumination levels at the task should be no greater than those recommended in Illuminating Engineering Society Lighting Handbook (fifth ed., 1972, p. 84-85) and no greater than 10 footcandles in nonworking areas such as hallways and corridors.

Discussion

No conclusive evidence is available to show harmful effects from either too much or too little light within the range found in commercial and industrial buildings. However, there are differences in lighting requirements for individuals; for example, older people generally need more illumination because of degenerative effects on pupil size, corneal transmission, visual acuity, scattered light, and muscular response. Both level and quality of illumination are important, however, since glare and other factors can make lighting offensive at both high and low levels.

Placement and orientation of luminaires and work stations with respect to each other are important in realizing energy savings. Work stations, places where the principle visual tasks are performed, are to be distinguished from general work areas, which surround work stations and which usually have lower illumination level requirements. Wherever possible, nonuniform lighting that is task oriented, with respect to both placement and illumination level, should be used. Uniform lighting systems which light large general areas independently of the task locations within them do not usually make the most effective use of energy. Coincidentally, the esthetic appearance of indoor space can often be improved by following nonuniform lighting practice.

Guidelines for efficiency in lighting

Selection of efficient lighting equipment

In the design of new lighting systems, and in modifying existing ones, the most efficient light sources that can provide the illumination required should be selected. As a general rule the efficiencies of some available lamp types rank according to the following list, with the most efficient first: high pressure sodium vapor, metal halide, fluorescent, mercury, and incandescent. In many cases replacement of existing low-efficiency lamp types with lower wattage, more efficient types will result in reduced total costs and improved lighting. See Table 3 for detailed examples.

Control and scheduling

Maximum control over lighting systems can be accomplished by having switches to permit turning off unnecessary lighting. Large general areas should not be under the exclusive control of a single switch if turning off small portions would permit substantial energy savings when they are not occupied. Lights should be turned off as a regular practice when buildings are not occupied, such as after working hours or on weekends and holidays. When opportunities for using daylight exist, natural light should be used whenever possible, and artificial lights should then be turned off. Occupants of buildings should be educated and periodically reminded to adopt practices which will save lighting energy, such as turning off lights when leaving a room.

Proper luminaire placement in the design of new lighting systems and the removal of unnecessary lamps in existing installations are examples of energy-saving measures. Luminaires should be positioned to minimize glare and veiling reflections, and work stations should be oriented and grouped to utilize light most effectively. Daylight should be used when available, maximum switching control should be provided to the user, and light colors should be used on walls, ceilings, and floors. Tasks should be designed to present high contrast to the observer.

Deterioration in illumination level due to dirt accumulation on lighting equipment should be prevented by adequate maintenance programs, cleaning lamps and luminaires, and replacement of lamps. As a part of maintenance programs, periodic surveys of installed lighting with respect to lamp positioning and illumination level should be conducted to take advantage of energy conservation opportunities as user requirements change.

Indirect impact of lighting energy on heating and cooling of buildings

The adoption of lighting energy conservation methods should be considered in conjunction with the operation of the heating and cooling systems. As a rule of thumb, when air-conditioning equipment is operating, each watt of lighting causes the expediture of about one-half watt of air-conditioning power. Substantial cooling energy can be saved by reducing electrical lighting loads to a minimum. Moreover, substantial savings in initial cost may be realized by reflecting the reduced heat load from an energy-conservative lighting system in the design of the air-conditioning system. Where possible, heat removal techniques should be considered to conduct waste heat from lighting systems out of the building without imposing an additional load on air-conditioning equipment.

The heat gain from lights should be included in calculating heat load; in addition, schemes utilizing waste heat from lighting are encouraged. Reliance on heat produced by lighting systems, beyond that produced by systems operated in normal energy-conservative ways, is not generally encouraged.

Measurement of recommended lighting levels

Light levels can be determined with portable illumination meters such as a photovaltiac cell connected to a meter calibrated in footcandles. The light meter should be calibrated to a basic accuracy of ±15 percent over a range of 30 to 500 footcandles and ±20 percent from 15 to 30 footcandles. The meter should be color corrected (according to the CIE Spectral Luminous Efficiency curve) and cosine corrected. Measurements refer to average maintained horizontal footcandles at the task or in a horizontal place 30 inches above the floor.

Measurements of work areas and nonworking areas should be made at representative points between fixtures in halls, corridors, and circulation areas. An average of several readings may be necessary. Daylight should be excluded or corrected for during illumination-level readings for a determination of level when the system is operated without available daylight.

Table 1 shows levels for office work that are recommended when work stations are occupied; otherwise, consideration should be given to turning lights off or to switching to 30 footcandles if other workers remain nearby. For tasks requiring levels higher than 50 footcandles, switching to lower levels is desirable if the work changes to less critical tasks. Illumination at the task should be reasonably free of veiling reflections and body shadows. Refer to Table 2 for guidance in determining visual difficulty of office tasks. Levels for industrial work are from the American National Standards Institute A11.1-1973, June 1973, Practice for Industrial Lighting.

Table 2 may be used as a guide in evaluating the degress of visual difficulty for office work. It is based on the concept that visual difficulty for this kind of work is not only a function of the intrinsic characteristics of the task and the lighting system, but also of the length of time the task must be performed.

To use this table, multiply the difficulty rating, as shown in the table, for each task performed at a given work place by a single worker times the number of decimal hours per day it is performed, for example, 3 hours 15 minutes = 3.25 decimal hours. Add the products for each task. If the sum is greater than 40, provide 75 footcandles on the work station. If the sum is greater than 60, provide 100 footcandles on the work station. Multiply the difficulty factors by 1.5 if the operator is over 50 years of age, or if he has uncorrectable eyesight problems.

Relamping opportunities

Relamping to a lower wattage can save substantial amounts of energy. For example, relamping from a 150-watt to a 75-watt bulb saves 50 percent of previous use, or relamping fluorescents to smaller wattages called "watt misers" or "econo-watt" (industrial trade names) will save energy. Relamping two lamps with one can save also. For example,

Table 1: Recommended maximum lighting levels

Task or area	Footcandle levels	How measured
Hallways or corridors – – – – –	10 ± 5	Measured average, minimum 1 footcandle.
Work and circulation areas surrounding work stations – – – – –	30 ± 5	Measured average.
Normal office work, such as reading and writing (on task only), store shelves, and general display areas – – – – – – – – – – – –	50 ± 10	Measured at work station.
Prolonged office work which is somewhat difficult visually (on task only) – – – – – – – – – –	75 ± 15	Measured at work station.
Prolonged office work which is visually difficult and critical in nature (on task only) – – – – – –	100 ± 20	Measured at work station.
Industrial tasks – – – – – – – – –	ANSI-A11.1-1973	As maximum.

Table 2: Relative visual task difficulty for common office tasks

Task description	Visual Difficulty Rating
Large black object on white background – – – – – – – – – – – – – – – – –	1
Book or magazine, printed matter, 8 point type and larger – – – – – – – – – –	2
Typed original –	2
Ink writing (script) –	3
Newspaper text –	4
Shorthand notes, ink –	4
Handwriting (script) in No. 2 pencil –	5
Shorthand notes, No. 3 pencil –	6
Washed-out copy from copying machine – – – – – – – – – – – – – – – – – –	7
Bookkeeping –	8
Drafting –	8
Telephone directory –	12
Typed carbon, fifth copy –	15

replacing two 60-watt lamps with one 100-watt will save 12 percent of previous usage and will normally provide the same amount of light as before.

Table 3 lists some illustrative examples of changes that can be made in installed lighting systems. They result in roughly the same illumination levels, but reduced energy consumption.

THERMAL OPERATIONS

Background

Of all the energy consumed nationwide 16 percent is used to heat and cool commercial and industrial buildings. Increasing the efficiency of heating and cooling equipment and exercising better control over operating and temperature settings can save significant amounts of fuel oil, natural gas, and electricity.

By adjusting thermostat settings to less energy intensive levels, substantial energy savings can result. In heating, each degree drop in temperature can result in approximately a 3-percent energy savings. In cooling, each degree rise in temperature can result in approximately a 3-percent saving in energy.

The heating and cooling guidelines outline measures that will normally result in appreciable energy savings. Modern heating and cooling systems are complex and interact with other aspects of buildings operations. Therefore, these guidelines can sometimes be supplemented with other measures after a detailed engineering survey of a particular building has been done by qualified experts.

Guidelines for energy conservation in operating cooling and heating systems

Cooling systems

During summer, air-cooling systems should be held at not lower than 78-80°F during working hours. Necessary adjustments should be made to cooling system controls so that space temperatures are maintained at 78-80°F with no reheat.

Humidity control

Humidity control on cooling systems should be eliminated for general office space. Requirements for humidity control in special types of space or locations should be handled on a case-by-case basis by the official responsible for the operation and maintenance of the facility; use of heating energy (other than waste heat) for such cases should be avoided.

Table 3: Relamping opportunities
[All costs are figured at 3 cents per kWh. The annual savings include normal ballast loss]

Change office lamps (2700 hours per year) from	to	to save annually
1 300-watt incandescent	1 100-watt mercury vapor	$14.58 (486 kWh)
2 100-watt incandescent	1 40-watt fluorescent	$12.00 (400 kWh)
7 150-watt incandescent	1 150-watt sodium vapor	$70.80 (2360 kWh)

Change industrial lamps (3000 hours per year) from	to	to save annually
1 300-watt incandescent	2 40-watt fluorescent	$18.69 (623 kWh)
1 1000-watt incandescent	2 215-watt fluorescent	$48.51 (1617 kWh)
3 300-watt incandescent	1 250-watt sodium vapor	$54.18 (1806 kWh)

Change store lamps (3300 hours per year) from	to	to save annually
1 300-watt incandescent	2 40-watt fluorescent	$20.55 (685 kWh)
1 200-watt incandescent	1 100-watt mercury vapor	$7.92 (264 kWh)
2 200-watt incandescent	1 175-watt mercury vapor	$20.10 (670 kWh)

Heating systems

In the winter, heating temperature control devices should be set to maintain temperatures of 65-68° F during working hours and should be set to maintain temperatures of not more than 55° F during nonworking hours. During working hours temperatures in warehouses and similar space should be adjusted lower than the 65-68° F range depending on the type of occupancy and the activity in the space. Cooling energy should not be used to achieve the temperatures specified for heating.

Humidity control

Humidity control should be eliminated for general office space. Requirements for humidity control in special types of space will be handled on a case-by-case basis by the official responsible for operation and maintenance of the facility.

Windows

Window draperies and blinds should be used to cut down heat losses by setting them to the closed position during nighttime and on cold, cloudy days and by setting them to the open position during periods of sunshine (subject to control of glare).

Heating blowers, threshold heaters, and portable space heaters

These devices should not be used unless there is no other heating source available.

Outside air intake

Outside air intake during heating and cooling seasons should be reduced to the greatest extent feasible. Under most conditions a 10-percent outside air intake will be adequate for general office space. Under certain outside air temperature and humidity conditions, the use of up to 100-percent outside air will be the most energy economical method of operation. Special purpose space such as laboratories or the like should have the outside air intake reduced to the maximum extent possible consistent with operating requirements.

Interior or core systems

Interior space in office buildings tends to have a heat build-up generated by lights, people, and equipment and does not require an added heat source during the heating season. Systems serving space of this type usually utilize recirculated air mixed with some outside air for ventilation. The amount of outside air should not be increased nor should refrigeration be introduced for the sole purpose of lowering the temperature which might otherwise exceed 68° F. Heat redistributed from the interior zone to the perimeter can be an important factor in energy conservation.

Perimeter zone systems

The function of perimeter zone heating is to offset the heat flow at exterior walls and windows and usually operates independently from the interior systems.

Exceptions

Exceptions to these techniques may be necessary to meet certain specialized requirements, such as for some kinds of equipment or other needs (for example, greenhouses, hospitals, and laboratories).

APPENDIX B.—Post-Symposium Statements Provided by Participants.

1. Overall Comments on NIOSH Symposium

   C. L. Crouch

2. Additional Symposium Notes

   John F. Halldane, Ph.D.

3. Concluding Statements for Proceedings of NIOSH Symposium

   H. Richard Blackwell, Ph.D.

4. General Services Administration Comments

   Harold Nelson

OVERALL COMMENTS ON NIOSH SYMPOSIUM

C. L. Crouch

I feel that the Symposium has been very worthwhile in bringing out all viewpoints even though they were conflicting. Conflicting views highlight the state of knowledge of a subject. In general, in the scientific world, this means there is not enough factual evidence for all people to unite in a conclusion. The greater the conflicting opinions the less the expressors know of the firm scientific relationships.

I believe that each participant did his best to develop material that would support his viewpoint, but if one looks at the evidence one realizes how meager it is and that it consists in many cases of isolated examples without the backing of an integrated fabric of functional relationships.

The publication of the views of the participants can be used in two ways: 1) that anyone or any agency with a given viewpoint can find comfort and psychological confirmation in the views of a participant whose views coincide, or 2) that not enough factual knowledge is evident from the whole seminar, and therefore specific research must be carried out to provide a sound basis for definitive conclusions.

I believe the hosts, the members of NIOSH, realized this because their exploration through personal contacts revealed there was no substantial body of knowledge from the literature which would adequately answer the question raised by GSA as to whether there is any health decrement due to lowered levels of illumination. While there has been much study devoted to visual performance, there has been little devoted to the health and safety aspects — only a few isolated and unrelated cases.

Discussion indicated a variety of viewpoints as to what is the definition of what affects health. Some would like to define it as permanent impairment of bodily functions, while others define it as an adverse change in function from the norm. Dr. Cohen of NIOSH brought out the World Health Organization's definition of health "which is not only absence of disease, but a complete state of physical, mental, and social well being." He further brought out, "A person who goes home with a tired feeling owing to the concentrated visual effort he has made during the day perhaps due to low levels of illumination would be covered by this type of definition."

Dr. David G. Cogan, probably representing the view of many ophthalmologists, admitted his lack of knowledge in the visual response field and expressed his opinion that there is no permanent or even temporary decrement in seeing under lower levels of illumination, and further, that there is no such thing as "eyestrain".

Dr. Glenn A. Fry, from Ohio State University, referred to Sir Duke Elder's (famous British Ophthalmologist) chapter on "Eyestrain" in his *System of Ophthalmology,* and he quoted Dr. Walter B. Lancaster's (famous ophthalmologist) description of eyestrain produced by faulty illumination. He then described by slides which mechanisms of the eye were subject to fatigue and eventual eyestrain.

Dr. R. A. Weale, Institute of Ophthalmology, University of London, described results of studies of reaction of the visual system to aging effects in the reception and response to light. He showed that the pupil size decreases and the transmission of the lens decreases. As a result, the visual acuity goes down, especially in later years. The time for response increases and the rate of adaptation is slower. All of this appears to involve, in his opinion, about three times as much light at sixty years as required at 20 years. This applies under "threshold conditions without taking into account what might be needed under higher levels."

C. L. Crouch gave the history of the development of the currently recommended levels of illumination and showed that their research basis involved only young, normal-vision college students with normal eye pause (1/5 second) and 99% probability of seeing for the average of the population of 20-30 year olds. The resulting working graph represents the threshold for these conditions. Meantime the factors for every 10 years older age interval are being developed through research by Mrs. O. M. Blackwell.

Dr. H. Richard Blackwell showed the results of his peoples' studies where he found that contrast of the detail with its background was the dominant factor in visibility; that the currently used field working curve of contrast versus luminance ((illumination) is located above the 50% probability of seeing curve by a factor of eight on the contrast scale for the average of the young population; that there is an enormous variation among individuals; that if the illumination was reduced to ½ of currently recommended values and applied to the variation in the USA population, some of the people would have a visibility level of two instead of eight and would scarcely be able to see; that Frederick Hebbard had found that levels of illumination lower than those producing a visibility level of eight had produced erratic fixation on the detail with the eyes making excursions back and forth; and that he (Blackwell) has just been able to confirm this before this meeting with a new Stanford Research Institute Eye Tracker. This erratic fixation movement produces a truly visual dysfunction for a part of the population and if prolonged over a period of working time could lead to all the symptoms of eyestrain (called "asthenopia" by the eye specialists).

Conclusion: While various participants expressed their own leanings and opinions, the above summary of their views leaves many questions as to whether these viewpoints have been proven. Some are merely expressing their preconceived judgments and seeking to justify them by segments of thought or isolated bits of laboratory information. There does appear to be evidence that older people need more light and that there is a wide spread of sensitivity in a given age group of the population. While as described above there is some evidence along these lines, too little is presently known for confident application. Laboratory techniques, sensitive equipment, and skills are now available for obtaining the knowledge of the effect of various levels of illumination on visual function and dysfunction and possible attendant eyestrain, especially on the less sensitive and older workers.

ADDITIONAL SYMPOSIUM NOTES

John F. Halldane, Ph.D.

It is quite difficult for NIOSH/GSA groups to extract the salient points from a discussion among the experts. Many of the points at issue are of detail, others of fundamental differences in philosophy of application.

A principle that Mr. Nelson stressed was that any guideline should be based on very simple monitoring systems. Immediately this means reconciling the well accepted photopically and cosine corrected incident photometer or "light meter" with a sophisticated photopically corrected telephotometer in order to relate monitoring procedures with experimental visual data. This can be done if we fully understand the assumptions relating the measures of the two meters. If the surfaces seen are perfectly diffusing, of *consistent reflection factor,* and the specular reflected *light from light sources is not directed into the observer's eye,* a measure of illuminance on incident photometers is meaningful. Unfortunately the last qualification is rarely achieved with the United States practice of extensive diffuse ceiling light.

The concept of "effective luminance" is not practical in GSA terms because it is not measurable directly but requires considerable experience in measuring with a telephotometer, summating the visual field luminance, working out a complicated formulation by hand or computer if it is economically feasible, and/or comparing a spatial configuration of light against a typical handbook distribution. It is very unfortunate that the disability glare factor (DGF) is based on a comparison illumination from *a perfectly diffusing hemisphere* because it represents one of the *worst lighting conditions.* Thus values of a disability factor are greater than unity for acceptable lighting conditions. Perhaps the best lighting condition for reference would be a perfectly diffusing hemisphere with a 30 degree black semicircular slot in the vertical plane to the surface and through the eye of the observer. Returning to the discussion, authough the DGF can exceed unity, we are assured by Dr. Blackwell that the disability glare factor (DGF) times the transitional adaptation factor (TAF) becomes unity in most diffuse lighting cases. It would be far better to have the best lighting conditions for a reference and the "effective luminance" would be the actual luminance. In this way designers, architects and even engineers would comprehend the significance of the concept.

In the NIOSH guidelines I would suggest that satisfactory lighting should achieve the following:

a. Task illumination to develop an effective contrast in the visual field This can be monitored through the use of an "illumination meter" "light meter", or incident photometer, all photopically and cosine corrected.

b. A minimum of reflected veiling light over the task. Consider the task surfaces as mirrors. If the reflection of the luminous sources are too evident they are likely to become a cause of disability glare.

c. Avoid strong contrasts in the whole visual field. Looking at a very luminous area like a luminaire, window, cloud, or water reflection can cause discomfort (discomfort glare, impeding photic response, pain) or visual disability (disability glare, transitional adaptation, after images, entoptic scatter). Some codes limit the changes in luminance by a factor of 10 to 1. Bare lamps should not be seen when viewing a task as their luminance area is too high.

Dark ceilings and walls, through insufficient illumination, can also provide excessive contrasts with task areas. Horizontal illumination should not dominate lighting considerations. Recessed luminaires in the ceiling are generally a problem.

d. Avoid completely diffuse lighting. Diffuse lighting reduces shadows and therefore reduces depth cues. Such environments appear "flat". The symposium seemed to confirm the European approach to lighting. Lower general lighting and maintained or higher task lighting for older people is appropriate.

Daylight and "permanent supplementary artificial lighting installation" (PSALI) have not been developed in this country. With the GSA order many offices are *relying on daylight*. In field monitoring of illumination levels the presence of daylight must be noted.

In safety problems it is important to differentiate between impeding and impairing behavior or physiological responses. The former is recoverable whereas the latter is irrecoverable from the causal cascade of the accident. Empirical research into behavior is restricted to impeding responses since legally and ethically one can not impair people. An impairing situation can only be reviewed from accidents or an extrapolation of impeding data. Thus experiments on safety in lighting are restricted to impeding perception, overt behavior, or physiological responses. Threshold visibility, inability to perform tasks, and photic discomfort studies are as far as one can go experimentally.

Research items should include the definition of human responses affected by electromagnetic radiation as the essence of evaluating an environment. We have contour visibility (Dr. Blackwell); perhaps clarity (Dr. Yonemura); photic responses (Dr. Fry, Dr. Halldane) in relation to glare, ocular pain and phototropisim, the luminosity; hue and saturation of color, shading with respect to light direction (Dr. Halldane), to erythemal responses (skin reddening to UV radiation), flicker, depth cues, window view, etc. Special tasks like glass blowing should be addressed. Work motivation under various lighting situations is important. In a report to Dr. Rubin (NBS) I discussed psychological time as a possible means of assessing motivation to work.

I would like to mention that the international CIE, Study Group A on "Psychological Problems in Lighting" is recommending to the CIE Commission that it becomes a Technical Committee. From the Montreal meeting one of the missions will be to consider the visual implications of energy conservation programs.

My intention is to present a paper, "Energy Conscious Designs in Lighting for People" at the CIE Plenary Session in London, during September 1975. The Design Methods Group is having a workshop on design methods for energy conservation in buildings, July 9, 1975 in Berkeley. Donald Widmayes and myself are submitting an entry concerning, "Lighting Conservation with Reflectors that Substitute Fluorescent Lamps—Economics and People's Responses."

CONCLUDING STATEMENT FOR PROCEEDINGS OF NIOSH SYMPOSIUM

H. Richard Blackwell, Ph.D.

I welcome this opportunity to summarize the points which I tried to make during the discussions in Cincinnati, and to put these points into the context of developments in the energy conservation and lighting field which have occurred since last summer.

The need for the strictest conservation of energy is even more obvious now than it was last summer. Thus, in the best interests of the nation, every effort should be made to regulate energy consumption. Important energy savings can be achieved by regulating lighting practices without loss in the quality of our living standard. How can this be achieved? Through the use of technological tools for lighting design and evaluation, the development of which has been proceeding apace for many years and is now nearing completion. Let me describe the current status of these technological tools.

We now know that the quantitative return in human performance achievable by expending energy for lighting is highly variable from situation to situation. The principal beneficial effect of increased levels of lighting is an improvement in the efficiency of the visual sensory functions underlying information acquisition. The extent to which improvements in sensory efficiency will provide improvements in overall human performance depends upon (a) the physical characteristics of the visual detail of a task (size, contrast, legibility); (b) the conditions of visual information acquisition implied by the task (time available, search involved, informational content); and (c) the extent to which the visual sensory efficiency affects overall performance of the task. The significance of human performance errors also varies from situation to situation. Since last summer, a quantitative method has been worked out for describing different levels of each of these four variables. We can now look forward to development of an engineering application method for allocating energy selectively in proportion to the quantitative return in human performance it will provide under each of a number of situations. This highly selective system of lighting standards will presumably replace the present system of standards in which energy is allocated selectively only in terms of the physical characteristics of the visual display. This use of an increasingly complex technology will doubtless increase the cost of lighting design services, at least initially, but the cost should be recovered through lower energy costs when the system is in operation. Of course, quite apart from cost, the introduction of a more highly selective set of lighting standards will save appreciable amounts of energy where it can best be spared.

It is also worth remembering that light levels as such are poor predictors of human performance, since the visual sensory functions affecting performance depend upon the spatial pattern of illumination far more than the level of illumination. It is for this reason that the Illuminating Engineering Society has moved toward prescribing lighting needs in terms of Equivalent Sphere Illuminance (ESI) rather than in terms of "raw foot-candles" as in the more distant past. ESI is a visual measure of lighting effectiveness, whose definition is based upon Report No. 19 of the International Commission on Illumination (1972). Lighting systems with technologically developed optical properties can lead to greatly increased values of ESI per watt. Since ESI describes the effectiveness of lighting to the eye, its use should be mandated in the interests of energy conservation. There is no doubt that substitution of ESI lighting standards for raw footcandle standards can lead to much more effective use of energy for lighting. Indeed, ESI standards can be reduced below raw footcandle standards without loss of visual benefits currently enjoyed. ESI illumination is quality illumination and, with quality, it is possible to reduce quantity. Here again, technological costs of lighting design will rise somewhat but these will be recoverable through less cost for energy, and there will be energy conservation in addition.

The strictest application of these new technological tools can lead to significantly reduced energy consumption without any reduction in visual benefits below those currently enjoyed by our population, operating as it does under lighting prescribed by present less-sophisticated methods. In such an event, it might seem that we could safely conclude that there are no health hazards in conserving energy used for lighting by the application of these new technological tools. Actually, we do not know that health and performance aspects of lighting run parallel, so that we cannot reach this conclusion with certainty. Furthermore, future needs may arise for even more energy conservation than is presently contemplated, so that lower standards of human performance may have to be contemplated. We need to know if there are health hazards to be expected in addition to losses in human performance as we contemplate cutting and cutting again the energy available for lighting.

It seems quite clear that reduced light levels, whether specified in terms of ESI or raw footcandles, do not produce any anatomical or physiological damage to the eye. Indeed, the possibility of such damage appears to exist only with excessively high levels of light. We may thus ask on what basis we might expect health hazards from reduced light levels. Some of the workers who have been subjected to reduced light levels during the past year have complained of "tired" or "strained" eyes, of headaches, and/or of general malaise. We may wonder whether these are genuine symptomatic complaints of visual stress and dysfunction and, if so, where lies their origin. It seems clear that, if the complaints are genuine, their origin most likely lies within the oculomotor systems which adjust ocular accommodation (where any exists), ocular convergence, and fixational eye movements. Discomfort can arise in the ocular muscles which operate these systems. Stress could arise in the CNS centers which mediate the highly complex servo control of these functions.

It cannot be denied that light levels affect the accuracy of these oculomotor functions, with finer adjustment accuracy made possible by higher light levels. There is one piece of evidence suggesting that the accuracy of these oculomotor adjustment functions runs parallel with the sensitivity of visual sensory functions. If this were the general rule, then performance criteria could perhaps be used to predict the likelihood of health hazards. Even so, however, we would need some idea of the performance criterion limit below which health hazards might be expected to occur.

It is now well established that individual members of the population have surprisingly large differences in their needs for lighting, so far as performance goes. Individuals of the same age group exhibit large random differences from each other. In addition, there is a progressive trend for older workers to need ever-increasingly higher light levels. We can identify the causes of the age effect as including the following: (a) the older the eye on the average, the less light is transmitted to the retina both because of increasing density of transparent optical components of the eye and because of decreasing pupillary aperture with age; (b) the older the eye on the average, the less the image contrast because of increased ocular light scatter within the transparent optical components of the eye, and the greater the light level must be to compensate for the loss in image contrast by an increase in contrast sensitivity; (c) the older the eye on the average, the lower the contrast sensitivity and the greater the light level must be to compensate; and (d) the older the eye on the average, the less accurate are the oculomotor functions and the higher the light level must be to compensate.

It is becoming increasingly possible to describe the populational differences in human performance to be expected with the use of any light level for a particular task situation. It is becoming quite obvious that even current "un-reduced" light levels result in some members of the working population having to perform some tasks under markedly disadvantageous lighting conditions. Predictions are clear that these numbers will increase if and when lighting levels are reduced. Of course, the question of interest to NIOSH is not how well workers can perform, but are there significant signs of stress and dysfunction which constitute health hazards. All we can say at this point is that it seems likely that current light levels result in conditions for some individuals in which the accuracy levels of their oculomotor adjustment functions are relatively poor and that the number of such individuals will be increased if and when light levels are reduced. What we do not know is whether or not a relatively low accuracy of functioning of the oculomotor adjustment functions can lead to symptoms of "tired" or "strained" eyes, or to symptoms of headache and/or general malaise. It seems that only an in-depth new research study can provide this information.

In setting up such a research study, care should be taken to avoid the a priori conclusion that symptoms arising from reduced light levels must necessarily be produced by reduced accuracy of the oculomotor adjustment functions. The research question is primarily whether or not there is any evidence of stress or dysfunction resulting from reduced light levels. It is only a presumption that, if there is stress or dysfunction, it will be related to reduced accuracy of the oculomotor adjustment function. The study should include use of direct symptomatic reports from workers required to perform for realistically prolonged periods under unreduced and reduced light levels, and a variety of measures of possible stress and dysfunction both during the time of reduced light levels and following restoration of unreduced light levels. Such measures might well include physiological indicators such as heart rate and blood pressure, biochemical indicators such as the ketosteroids, and psychological indicators such as abilities to learn and reason. In making such tests, it would seem most appropriate to measure also the accuracy of both the oculomotor adjustment functions and the visual sensory functions related to information acquisition, since there may prove to be useful relations between one or another of these measures and the measures of stress and dysfunction.

UNITED STATES OF AMERICA
GENERAL SERVICES ADMINISTRATION

Public Buildings Service
Washington, DC 20405

DEC 23 1974

Dr. Wordie H. Parr
National Institute of
Occupational Safety and Health
1014 Broadway
Cincinnati, Ohio 45202

Dear Dr. Parr:

Upon review of the material presented at the NIOSH conference on "The Effects of Reduced Levels of Illumination on Occupational Safety and Health," we wish to submit the following post conference statements.

It is our conclusion that for the vast majority of the population and work task and programs conducted in Federal space, the present energy conservation lighting levels of 50 foot candles at the work place with 30 foot candles for background illumination and 10 foot candles in corridors and passageways are logical and not only in consort with good health, but generally will not result in any reduction in worker efficiency, effectiveness, or any fatigue, or strain on the individual employee. Any adverse impact on the healthy population's ability to see is at lighting levels considerably below the currently established Federal buildings levels.

Exceptions to the above general statement will occur in a few special cases either as a function of the individual work task difficulty or individual vision impairments of specific employees. From a practical light management aspect, these individual cases can best be handled by task oriented lighting at the individual's work place.

While the conference did not completely describe the factors controlling task difficulty, the prime factors currently recognized are the degree of contrast, the fineness of the work, and the time spent at a particular task. These factors relate not only to ability to accomplish work, but also the speed at which printed or written material can be handled in a job situation.

Individual vision impairments, other than those readily correctible by eye glasses, were primarily related to the age of the individual. Most of the data presented at the conference indicated a definite dropoff in visual acuity starting at about age 60, but having an important impact in reduced vision at age 70 and above. The attached graph titled "Federal Civilian Employment by Age," points out that a very small percentage of the

Federal population is in the age group where the majority of persons have a tendency towards vision problems. This is not to indicate that vision problems are to be ignored, but rather that they can be expected to be an extremely small percentage. The provision of individual illumination to assist these persons will make no significant impact on energy resources.

The conference produced the above generalized information which will be extremely helpful in administering energy conservation programs. It did, however, point out the lack of the specific type of data that will eventually be needed by the individual building, plant, or other manager charged with the responsibility of assuring proper illumination with maximum energy conservation.

Much additional engineering and field application data is needed. It is recommended that NIOSH conduct or encourage research and development in the areas of:

(1) Obtaining definitive information on both the factors and measurements of the factors that determine the visual difficulty of specific work situations, particularly the interrelationship of contrast, time, and fineness of work.

(2) Developing screening methods and mechanisms for measuring the capability of individuals to use their eyes in collecting data from a work situation and the resulting impact on the person of that action.

(3) Production of a definitive statement of the impact of illumination of specific work situations and visual capabilities and the minimum needs of the individual required to do the work in a safe and healthful manner.

It is essential that the results of the recommended research and development be effectively useable by technicians in the field.

Sincerely,

Harold E. Nelson

HAROLD E. NELSON
Director, Accident and
Fire Prevention Division

Enclosure

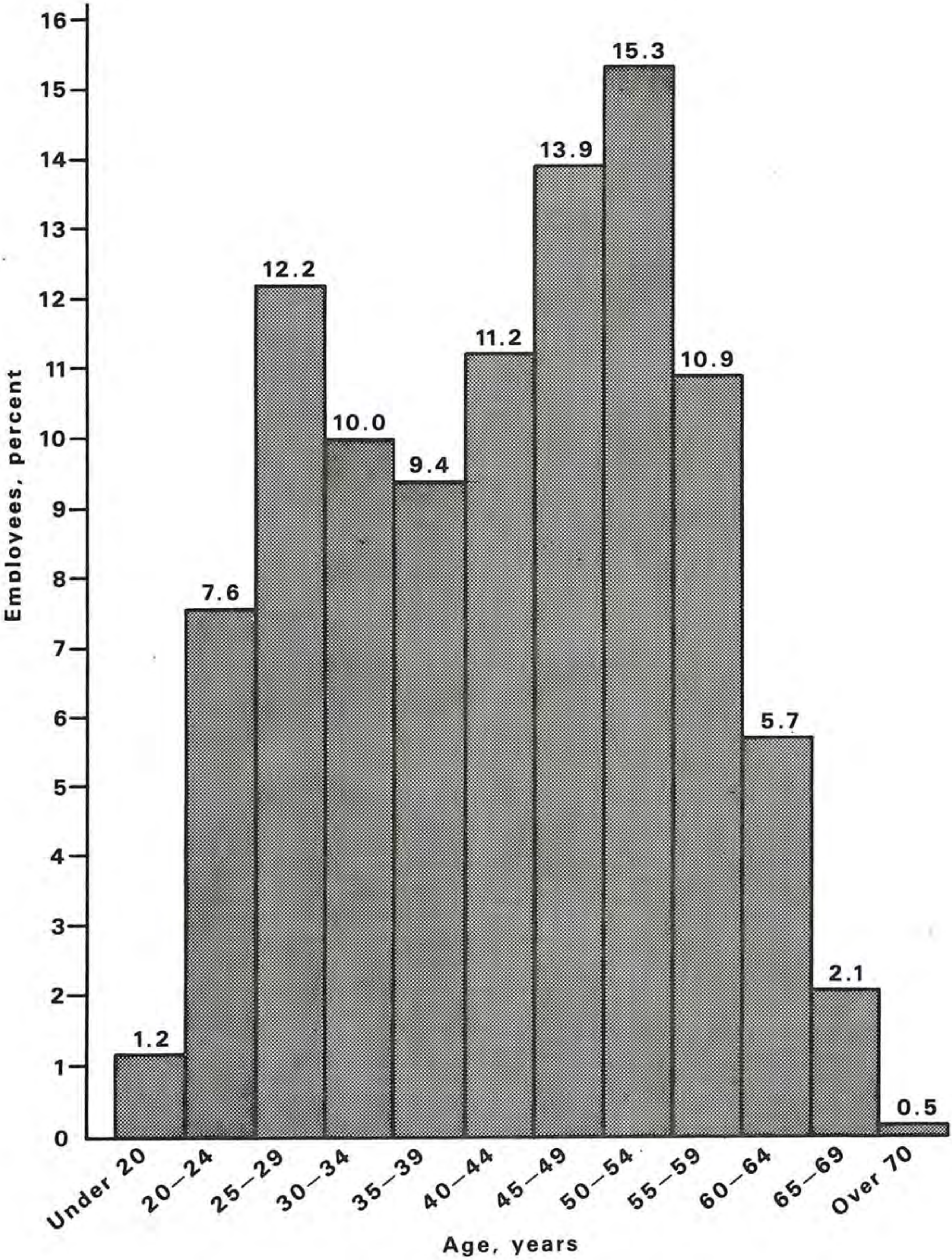

FIGURE 1.—Federal civilian employment, by age.

APPENDIX C.—Additional Attendees Participating in the Discussions.

Dr. William Bensen, Executive Secretary—NAS-NRC, Committee on Vision, Washington, D. C.

Paul Caplan, Deputy Director, Division of Technical Services, NIOSH.

Alex Cohen, Ph.D., Chief, Behavioral and Motivational Factors Branch, NIOSH.

Francis Dukes-Dobos, M.D., Chief, Physiology and Ergonomics Branch, NIOSH.

Robert Hughes, Mechanical Engineer, Engineering Branch, NIOSH.

Jeffrey Lee, Deputy Chief, Western Area Laboratory for Occupational Safety and Health, NIOSH. Salt Lake City, Utah.

Leonard C. Mead, Ph.D., Chairman, IERI Board of Trustees; Professor of Psychology, Tufts University, Medford, Massachusetts.

Richard Pronk, Chief, Energy Utilization Branch, Office of Buildings Management, General Services Administration, Washington, D. C.

Donald K. Ross, Sc.D., Ross and Baruzzini, Inc., Consulting Engineers, St. Louis, Missouri.

John Talty, Chief, Engineering Branch, NIOSH.

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NIOSH

Administrative Report