

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 inter-

pretation 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 approximation, 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

SAFETY AND HEALTH EFFECTS OF REDUCED ILLUMINATION

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 suprathres-

hold 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/\bar{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, \bar{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 \bar{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 \bar{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 \bar{c} as you change the size of the E. My wife did these experiments, and so it is an inter-related 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 supra-threshold 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 supra-threshold 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/\bar{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 \bar{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/\bar{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

SAFETY AND HEALTH EFFECTS OF REDUCED ILLUMINATION

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 spatial 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 dy-

namic 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.

SAFETY AND HEALTH EFFECTS OF REDUCED ILLUMINATION

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 re-

quire 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.

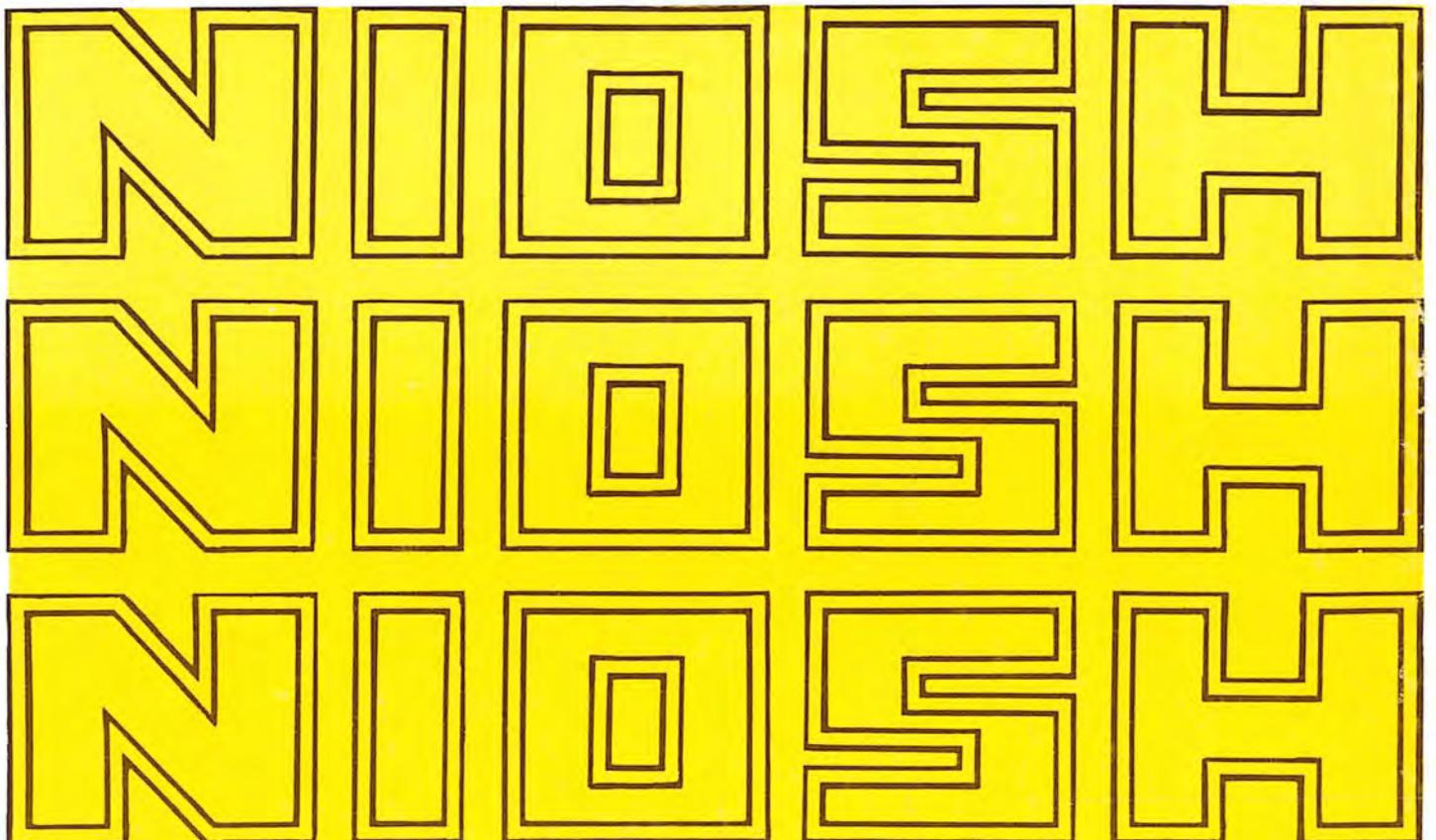
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