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

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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 pro-

duced 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 ear-

lier, 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 meas-

ure 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 toxi-

cological. 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.

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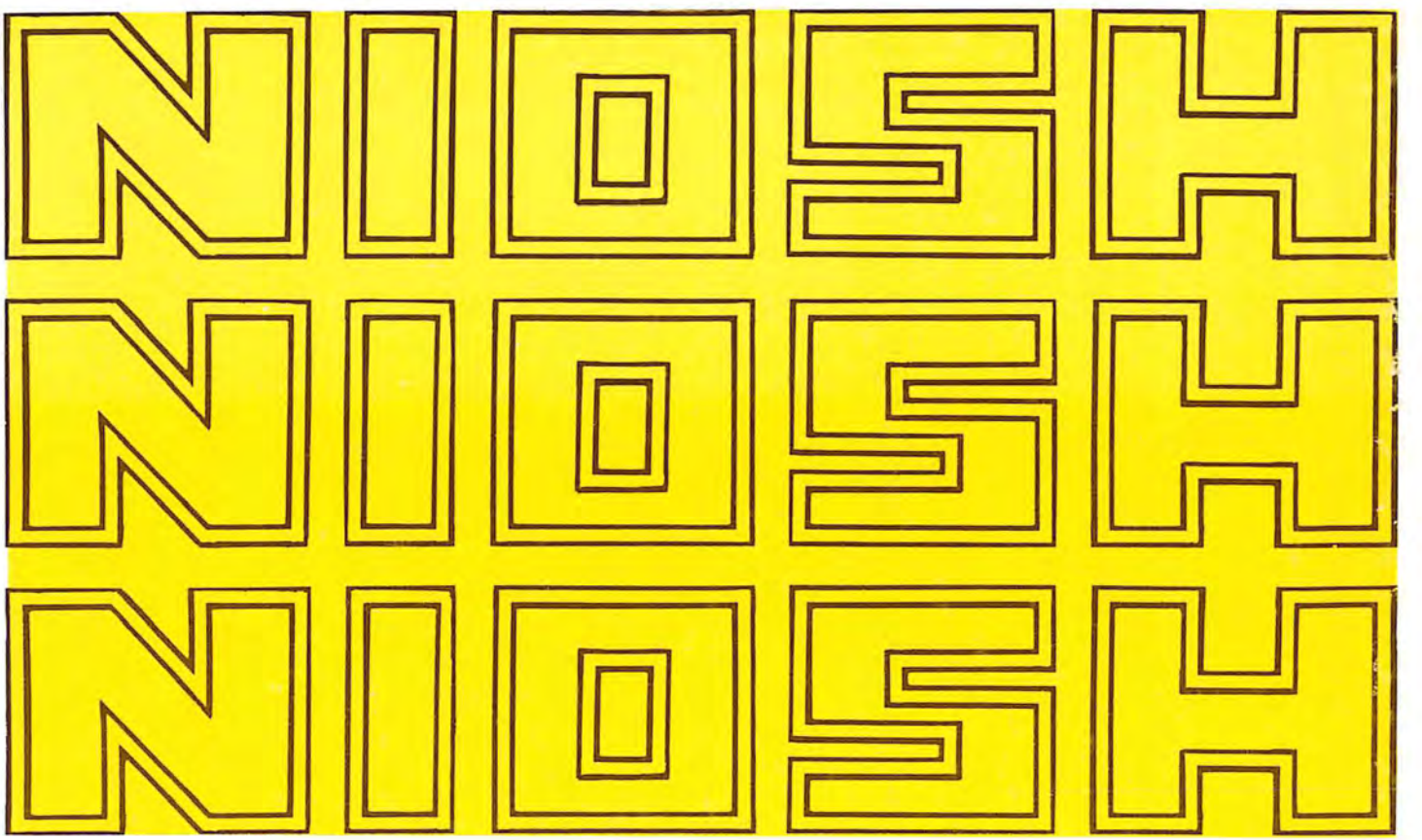

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