Psychophysical Analysis of the "Sensation of Reality" Induced by a Visual Wide-Field Display

By TOYOHIKO HATADA, HARUO SAKATA, and HIDEO KUSAKA

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This report summarizes research on the psychological effects induced by certain parameters of visual wide-field display. These effects were studied by means of three different series of experiments. The first experiment series evaluated the subjectively induced tilt angle of the observer's coordinate axes when presented with a tilted stimulus display pattern. The second experiments were to determine the observer's eye and head movements for information acquisition when presented with a visual wide-field display. The third series of experiments was to determine, by means of a subjective 7-step evaluation scale, the viewing conditions under which the display induces a sensation of reality in the observer. From the results of these experiments it was concluded that a visual display with horizontal viewing angles ranging from 30° to 100° and vertical angles from 20° to 80° produces psychological effects that give a sensation of reality.

When new information is presented to an observer, he may sometimes wish to receive such information at a distance closer to the information source, and at other times he may wish to add his own observations to the information presented and freely associate them with that information. At present, the first case is represented by television, which gives high-density information similar to the real image sources in real time, and the second case by newspapers and other printed media using typeset characters and photographs.

With the advancement of new technologies, broadcasting has now developed such procedures as teletext, facsimile, and home video, adding to television some of the characteristics of the print media. They were intended to improve the quality of information and increase the degree of freedom in obtaining the information.

With regard to the first wish, that of coming closer to the information source, does today's TV broadcasting serve the purpose properly? Monochrome has advanced to color, and the size of the display tube and the sharpness of the image have improved appreciably. Added to that, the miniaturization of broadcasting equipment has made possible the speedy and immediate coverage of events. However, when it comes to a more faithful presentation of the information, something is still wanting in television.

For example, in the TV reporting of a sports event in progress, several cameras, some with super-telephoto zoom lenses, may be used to keep track of the progress of the game; but close-ups cannot present the scene as a whole (and the TV spectator may miss out on something happening out of the range of the camera), while long-shots cannot show the facial expressions of individual players (and the TV spectator may miss out on an interesting player reaction). To overcome these shortcomings of the medium the image is sometimes divided up and two cameras are used. However, this method still has its limits, and the observer cannot become as enthusiastic as he would while actually sitting at the stadium and being able to freely direct his attention toward any part of the scene. Is it impossible to transmit simultaneously with several cameras and enlarge any part of the scene that the observer would like? Apparently there exists an underlying desire for widening the camera angle and making the TV screen much larger so as to show with great clarity the scene as a whole.

For the inception of a broadcasting system that induces in the observer an active attitude toward the perception of information, the image display technology must be improved first. At present, efforts for a more "natural" picture presentation are made with regard to the aspects shown in Table I.

In the case of sports coverage mentioned above, enlargement of part of the scene by the TV spectator as he is watching the long-shot scene of a game will require the improvement of picture sharpness and provision of a larger display screen, shown in Table I(a). To give a feeling of the vast-

A contribution received on 22 October 1979 from Toyohiko Hatada, Haruo Sakata, and Hideo Kusaka, Auditory and Visual Information Processing Research Group, Broadcasting Science Research Laboratories at the Japan Broadcasting Corp. (NHK), 1-10-11, Kinuta, Setagaya-ku, Tokyo 157, Japan.

ness of the arena a three-dimensional display presentation system, shown in Table I(b), is desirable so as to not fatigue the observer. Furthermore, to make it possible for the viewer to choose the observation point he likes best and thereby achieve a greater sensation of reality, the improvements cited under (b) and (c) in Table I are necessary.

It can easily be seen that for the realization of even the least of the above cited improvements a visual wide-field display will be most effective. (See items marked with an asterisk in Table I.) The wide-field display is technologically feasible and it is capable of inducing strong psychological effects.

From this point of view we will first summarize what psychological effects the observer will experience from a large television screen having a high definition image (realizable in the near future); then we shall report on the quantification experiments for these psychological effects. Because of a number of limitations in our experimental conditions, it still remains to be seen whether our experiments will be applicable in their entirety to a new type of broadcasting display. We will be happy if our report offers guidelines for the conception of future developments of the wide-field display.

Table I. Areas of possible technological improvements needed for the feasibility of the visual wide-field display.

Conformity with the visual perception functions	Conformity with the observing functions
(a) Upgrading of the existing pictorial information. (Improvement of picture sharpness, natural movement of objects, and display screen.*) (b) New reproduction modes of pictorial information. (Three-dimensional space information;* expansion of observer space* and time.)	(c) Display methods matching picture content. (Expansion of observer space* and time; active observing conditions; conformity of induced emotion and picture content, i.e. to establish empathy between the viewer and the director.)

*Denotes that these topics are especially relevant.

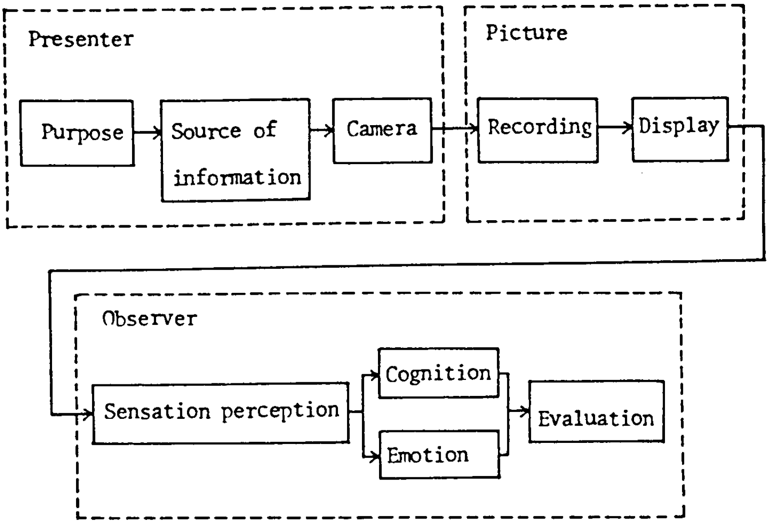

Fig. 1. System for the transfer of information from presenter to observer.

Relationships between Image Display and Conditions of Observation

An information system using pictures can be schematized as in Fig. 1 (Ref. 1). The question is: what effect will the displayed pictorial information have on the observer, and as a result, how will he evaluate the offered information? Of like importance is the problem of information source selection by the information presenter according to his purpose: what pictures will he present with regard to information content? At present, there exists no scale for the evaluation of those pictures. They may be evaluated on the basis of information efficiency at the time of observation, but if emotional and other factors are added, evaluation will become difficult because of the various factors involved. The same difficulties arise, of course, with regard to the relationships between display and observer, and the observer's functions may be simplified as in Fig. 1.

Cognition is to see an object and understand what it is. Emotion is to derive a powerful feeling of beauty or any other equivalent (or antithetic) sensation from what is seen. An evaluation scale for cognition can be based on the time of recognition and on the rate of correct observer answers given. This appears immediately obvious. For beauty, however, we can hardly find a concrete evaluation scale, even if we may feel intuitively that we understand it. To explain the word "beautiful," dictionaries use synonyms such as "pleasing," "lovely," "handsome," and "pretty," but concrete feelings differ in their degree, depending on the object seen and on the surrounding circumstances. (Webster's definition: "exciting aesthetic pleasure.")

Is it impossible then to have a standard for "beauty"? No, it is not! In beauty contests, the winner is chosen by seeing whether she has qualities strong enough to convince the contest judges, although some objections may be raised. This type of evaluation by a limited number of observers uses a subjective evaluation method, as is often employed in psychological experiments. It is certain that such a *subjective* evaluation method is effective in cases difficult to quantify. But, natural scientists tend to insist that an *objective* method must be found for examination of the process by which a human observer receives information and evaluates it. They also maintain that certain specific factors exert great influence on the psychological evaluation during the human observer's information processing.

For this reason, in studying the effect of a picture on an observer, one must separate the component factors of a picture and examine their individual effects, and not merely analyze the displayed picture as a whole. We shall now study the effect of a large-screen picture on an observer, breaking it down into component factors.

Factors Affecting the Visual Wide-Field Display and Their Psychological Effects

Figures 2 and 3 illustrate the psychological effects an observer will experience in front of a wide-field display. For the better understanding of their relationship, the presenter and the observer have been separated according to their different roles.

Display Factors of a Visual Wide-Field Display[2]

Factors on the image presenter side are (Fig. 2): the camera angle, θ_p, the pictorial composition within the information source, F, the display screen, DS, the image magnification, θ_p'/θ_p, and the projection magnification, L_p/L_f (where L_f is the distance from lens to film in the projector). They will briefly be discussed in the following.

Camera angle. This variable (θ_p in Fig. 2) determines what extension of the original object will be reproduced finally on the display screen. The amount of displayed information increases as the camera angle widens. On the other hand, wide-angle depiction of the scenery intended by the presenter may be less satisfactory, and overemphasis of perspective may result in image distortion. If only specific objects are pictured with a telephoto lens, it is unclear what other objects may surround them and what the general surroundings may look like. By skillful consideration of

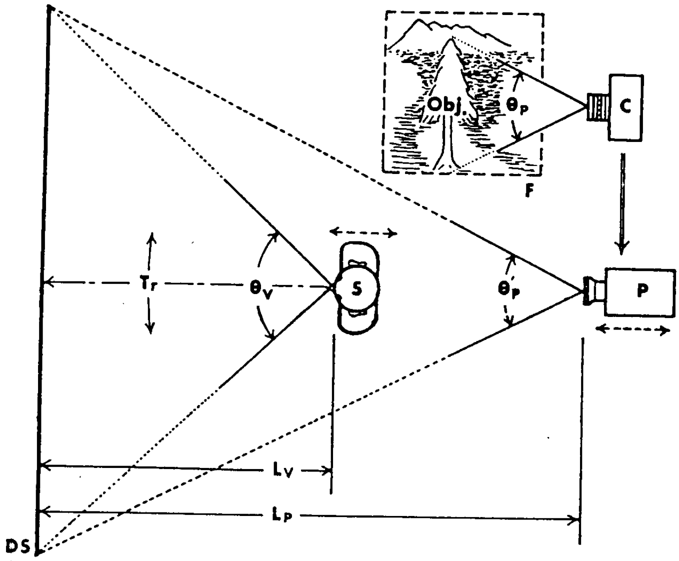

Fig. 2. Image display and observer in an experimental setup for measuring induced subjective effects. Photographic system: C, camera; F, picture composition; θ_p, camera angle. Display system: P, projector; S, observer; L_p, projection distance; L_v observer distance; DS, display screen; T_v, eye tracking; θ'_p, projection angle; θ_v, viewing angle.

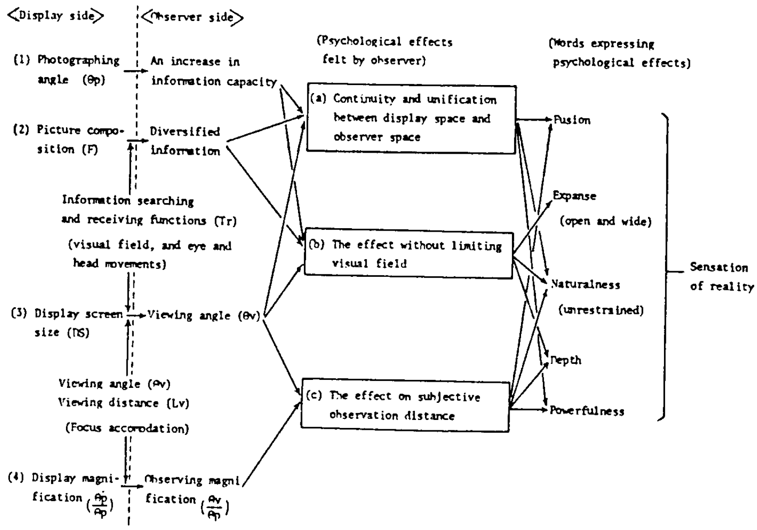

Fig. 3. The visual wide-field display and its psychological effects on the observer.

these points, striking pictures can be produced by selecting a lens suitable for the presenter's intention, and by choosing a suitable camera viewpoint. The skillful use of a zoom lens has an especially great influence on the subjective observing distance we discuss below.

If part of a wide-angle photograph could be enlarged, "blown up," within an improved high-definition display image, easy on the eyes of the observer, it could then become possible to give the observer a choice of information selection as he might wish. This would facilitate a more natural scene reproduction.

These considerations indicate that wide-angle photography is appropriate for expressing a sense of expanse and giving the observer a feeling of being included in the scene space displayed. However, it is still true that close-up shots from a distance are still needed for showing details of single objects and for emphasizing them. Nevertheless, one may assume that there is a camera angle at which objects look most natural, depending on their characteristics and on the presenter's aim.

Picture composition. This element (*F* in Fig. 2) must always be studied apart from wide-screen display. For instance, when shooting outdoor scenery from a moving car, pictures taken through a side window and showing road and buildings apparently moving past the observer will give a stronger sense of movement to observers facing the TV screen frontally than in-depth moving scenery as seen through the back window. This is so because the presenter and the observers are seeing the objects under the same conditions. There is no need for the presenter to look at objects always under the same conditions as the observers, but he must take note of the eye movements of the observer as he watches the moving landscape from a car window. His eyes will be in continuous movement. With a small TV screen, however, the angle of eye movement is much less. The observer, looking at the moving scenery on the screen, cannot have a sense of presence, even if he would turn his head from side to side. This indicates the importance of good conformity of the picture presentation technique with the observer's behavior — his eye and head movements for information acquisition.

For paintings and photographs, examples are often shown of "well-arranged" or "harmonious" compositions. Mostly, they are based on the artist's experience. Even the "configuration perception laws" of Gestalt psychology[3] have yet to reach a conclusion on how to deal with the visual function. (These empirical laws may be stated: "When man sees a collection of points or lines, (1) smoothly continuing curves look unified and their unification comes to an end at an angular part, (2) symmetrical parts appear unified, (3) an enclosed part looks unified against its outside, and (4) parts having orderly relations among their components, or presumed to have such relations in the future, seem unified. With these laws, we perceive points and lines collectively.")

Composition seems to have more to do with the way of perceiving and processing simultaneous information that enters the human visual field than with the searching function as stated above.

Functions of the retina. The functions of the various parts of the retina[4] determine the characteristics of the visual field. In the central area of the visual field, details and color of a figure pattern are detected with precision, but in the peripheral areas, more than 10° away from the center, visual acuity is poor and information is not perceived correctly (Fig. 4). However, if the functioning of the peripheral areas is eliminated completely, it then becomes impossible to read a letter that covers an area larger than the central area of the visual field. This shows that the peripheral areas play some minor role in the acquisition of information.[5]

Even if the viewing distance is changed, there is little change in the impression we receive from a given composition. From this we may assume that not only the information perception efficiency but also the information processing at a higher-level nerve center has something to do with composition. The relationship be-

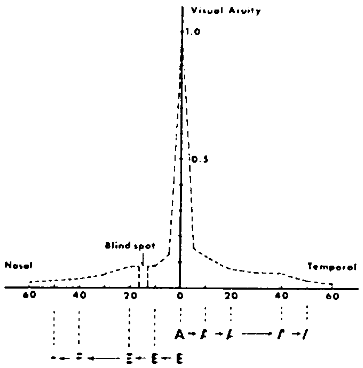

Fig. 4. Perception of the letters *A* and *E* by different areas of the retina (from Fukuda[4]).

tween the distribution of specific information areas over the entire scene, and the scene-display aspect ratio will be explained later.

Display screen. On a display screen (*DS* in Fig. 2) having a small format, be it a front projection screen or the Braun tube, a great amount of information displayed within a wide camera angle constitutes no more than a confused mass of information for the observer. For this reason, the size of the display screen and the viewing angle, θ_v, as determined by the viewing distance, become important factors.

The fact that wide screens have become popular over motion picture history indicates that the size of the display screen has a great psychological influence on the observer.[6] In the early stages of the "hologram," a type of stereoscopic photography which became popular some time ago, people were attracted by its novelty and were satisfied with its three-dimensional display of tiny objects like a toy. But by now they no longer pay attention to it unless life-size figures, not a small doll, are shown in three dimensions. Things familiar to us look unnatural when they are reproduced in an extremely large or very small size. For their reproduction in a size that appears natural, the size of the display screen and the magnification rate, $M = L_p/L_f$, exert great influence.

When the display is very large, its psychological effect is felt very strongly. One cause for this — it is pointed out — is that when we concentrate on the contents of a picture, we are hardly aware of the frame of the screen. With the disappearance of the frame that separates the picture display space from the observer surround space, the existence of the display screen itself becomes less noticed, and the contents of the picture appear to have depth and not be flat. This is well exemplified by the fact that when one observes a landscape photograph closing one eye, so as to not see the frame, the photograph looks as if it had depth.

Furthermore, by wrapping the display screen around the viewer, we can enhance the effect of continuity and unity of the display space and the observer space, as demonstrated by the Astrorama motion picture system.

Apart from the psychological effects described, a large display screen provides greater freedom for the viewer's visual selection. His eye movements are less confined by the screen, and his viewing angle expands on both sides. He acquires a greater sense of naturalness. But, when an object is moved laterally from one end to the other end of a large screen, the viewer must move not only his eyes as such but must also turn the head to follow the object on the screen. It must be noted that this increases the vividness of the action but it also increases the viewer's fatigue. We will describe further down in what way the eyes and the head move during the search for visual information.[7]

To diminish the presence of the display screen, some methods use a large convex lens or a concave mirror (Fig. 5), instead of the method of monocular observation for the suppression of the perception of the screen frame. The displayed virtual image appears in an enlarged size at a distance from the lens or the mirror. As a result, depth sensation and naturalness are felt more than by direct observation of the image.[8] This method is used for flight simulators and for virtual-image television projection.

Similar effects are obtained, though on a reduced scale, by placing a glass plate several centimeters thick over the displayed image, or by placing the frame of the projection screen or the TV display screen at a distance behind or in front of the display. Both arrangements make the viewer distance to the screen less precise.

Human capability for judging distances decreases if the displayed image is more than two meters away, and for that reason the impression that it is displayed on a screen weakens. A child absorbed in a cartoon show on television will move closer to the TV set, and even an adult may bring the book he is reading closer to his eyes despite the strain on his eyes. This indicates a desire to exclude unnecessary (irrelevant) information and fill the effective visual field exclusively with the wanted information despite the greater visual effort. From these facts it becomes evident that a large-screen display that broadens the viewing angle past a certain value will be effective, even if this requires an adequate viewing distance.

(The human capabilities for judging distance depend on the following: (1) accommodation of the crystalline lens of the eye — which also relates to depth of focus perception; (2) convergence of eye movement which occurs when one looks with both eyes at an object, especially at shorter distances; (3) disparities in the detection acuity of the binocular retina images; (4) motion parallex that detects changes in the relative positions of far and near objects through changes in the observer's position, etc.; (5) psychological effects coming from

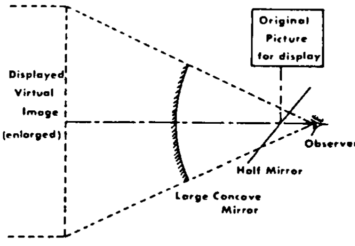

Fig. 5. Virtual-image wide-field display by means of a large concave mirror.

the observer's experience, etc. Of these, (1), (2), and (3) are seen to work effectively when the object distance is within about two meters for (1), within about five meters for (2), and within about ten meters for (3), respectively. Conditions (4) and (5) are effective up to fairly long distances, depending on the conditions.)

Image magnification. Its value can be expressed as the ratio of the projection angle to the camera angle, θ_p'/θ_p, (Fig. 2). If $\theta_p' = \theta_p$, and if the projection distance L_p equals the camera-to-object distance, the screen image size of the object will be equal to the original object size. As mentioned in dealing with the preceding factors, the displayed object size has a strong psychological effect on the observer. Often, in the last scene of a film, close-ups of the hero are cut to long-shots, and the hero's taking leave of the audience (which has identified with the hero) is made effective solely by progressively diminishing the figure of the hero on the screen.

Thus, the size of an object displayed within the picture influences the observer's subjective distance perception, and a change in magnification may give the observer a feeling of being included in the displayed object space, or conversely, a feeling that he is viewing the scene from a distance as an outside onlooker. Movements increase the impact of these effects. However, when the picture includes an object of a size familiar to the spectator, certain magnification rates will depict it in a natural way, depending on its surroundings.

Our explanations so far have been mainly given from the point of view of the presenter of the picture, placing emphasis on the factors existing on the presenter side. But, unless we thoroughly check the factors on the observer side, we will not be able to produce as much of an effect as we would want to achieve. It would be impossible, however, to define the observer conditions if we were to take into account such factors as family environment and mental state of the observer. Therefore, we have grouped the effects resulting from the various visual functions (visual field, searching movement, accommodations, etc.) and from display factors into three basic effects clusters (Fig. 3a, b, and c). We will report on this together with the results of the psychophysical experiments concerning these functions.

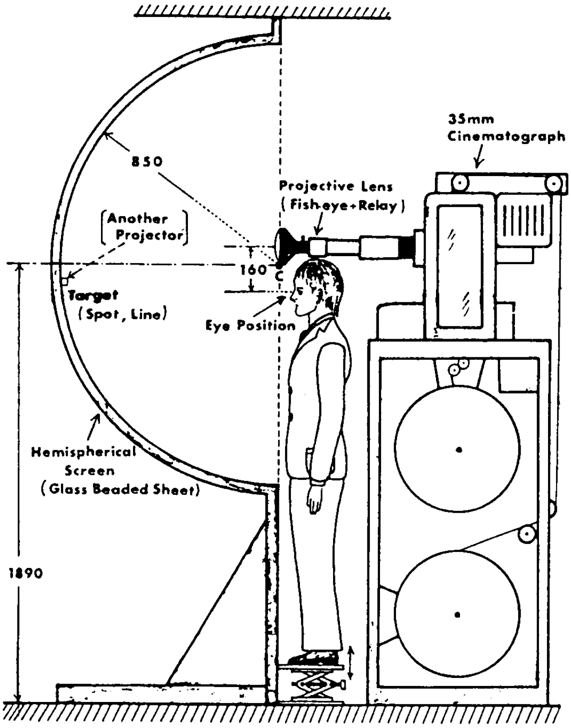

Fig. 6. Apparatus creating an experimental visual wide-field display. C is the center of curvature of the hemispherical screen. Numbers indicate dimensions in millimeters.

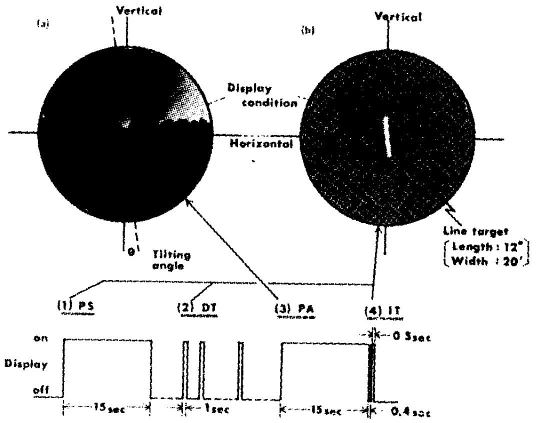

Fig. 7. Experimental procedure for measuring induced subjective coordinate axes tilt. PS, posture adjustment period of observer; DT, determination of detected tilt angle tolerance; PA, display interval of tilted picture; IT, detection of subjectively induced tilt angle.

Psychological Effects of a Visual Wide-Field Display

Unification of display and observer space. Under certain conditions, the display space and the observer space are unified and produce a feeling of seamless continuity under which the observer is presented with the information contained in the displayed picture. Suppose you stand in a train and look through the window at another train on an adjacent track. When the other train starts moving you might feel (relying only on your eyes) as if your own train had started moving. This is so because the information based on objective coordinates (lines of buildings and their movement, etc.), obtained by means of the visual sense, influences the condition of the observer's subjective coordinate axes, and as a result the observer might feel as if the space around him has changed into a condition different from that of the real space. Moreover, this effect is felt with greater strength when the observer's interest is strongly attracted by the object he is watching. This then will offer a suitable means for measuring the degree of sensation of reality awakened by the display, and we have conducted experiments along these lines as described in what follows.

Apparatus for creating an experimental wide-field display. In order to project a picture that covers the full visual field in front of the observer, a hemispherical glass-bead concave screen was used (Fig. 6). The projection lens of the projector used was located near the center of curvature of the screen. Both the camera and the projector lenses were identical fish-eye systems with a 180° viewing angle and also a 180° projection angle. The observer was looking at the screen in a vertical posture with his eyes just below the projection lens system. To minimize distortion of the projected picture, the distance between the center of curvature C and both the center of the projection lens system and the eye position of the observer was less than 1/10 of the radius of curvature of the hemispherical screen.

Experimental methods. The physical coordinate axes of the projected picture were tilted in order to measure the maximum tilting angle for which the observer would still feel that his subjective coordinate axes were vertical (Fig. 7). The measurement procedure was as follows.

1. Under the condition shown in Fig. 7b, and without a visual picture display, the comparison standard physical vertical coordinate is shown by means of a line target. The observer will adjust his posture so that the tilted line target will appear vertical to him (*PS* in Fig. 7).

2. Under the same no-picture condition a determination is made of the direction at which the observer will subjectively feel that the line target is vertical, and it is ascertained that, for the given case, the line target tilt angle tolerance is no more than ±30′ (visual angle *DT* in Fig. 7).

3. For 15 s the observer is then shown a tilted picture display (*PA* in Fig. 7a) which induces the subjective coordinate axes.

4. Immediately after the inducing stimulus of the tilted picture is extinguished, the line target is shown to the observer, and it is found out at what tilt angle the observer will subjectively feel that the line target appears vertical (*IT* in Fig. 7). This process is repeated several times. The difference between the subjectively vertical tilt angles obtained in steps (2) and (4) will be the quantitatively measured effect induced by the picture. In subsequent experiments, display variables were changed for different measurement purposes (Figs. 8 and 9).

Experimental verticality tilt results. For more details on picture display conditions influencing the observer's subjective coordinate axes the reader may consult Ref. 2. Here we wish to discuss the changes that occur when the horizontal viewing angle (defined as θ_v in Fig. 2) is changed under which the picture display is observed. Plotting the viewing angle along the abscissa axis and the induced angle of subjective verticality on the ordinate axis (Fig. 8) demonstrates the effects of viewing angle variation due to differences in picture content. In the figure, the solid lines represent the experimental result induced by displaying ordinary landscape pictures (Fig. 9), and the broken line shows the result of displaying a parallel vertical grating pattern. The approximation formula $A = k \log(r^2/a + 1)$ was used to obtain the results shown as a broken line. In this formula, A represents the induced angle, r is the radius of the viewing angle, and k and a are constants.

In summarizing the results the following can be observed: (1) the effects on the observer will increase in proportion to the widening of the viewing angle; when the viewing angle exceeds a certain value a state of saturation is reached and no further changes occur; (2) the degree of the effect induced depends on the content of the picture — a picture composition containing pronounced perspective elements exerts a stronger influence on the perceived subjective coordinate axes; (3) when the displayed viewing angle is less than 20–30° the tilting effect is very small with a stationary picture display; (4) when the displayed viewing angle exceeds 80–90° little effect of the larger viewing angle is observable and a state of saturation is reached; and (5) for a common type of stationary picture, the viewing angle that exerts the strongest influence on the subjective coordinate axes perception is around 50°.

These experiments have not demonstrated a condition that could be exactly described as a sensation of reality in the true sense of the word, because only the vertical coordinate axis was selected and quantified as representing spatial information. On account of this, effects that can result in a sensation of wide open spaces, etc., are only minimally induced in this experiment. With regard to this point we are trying to achieve quantification by using stimuli from moving images and measuring the evoked visual responses.

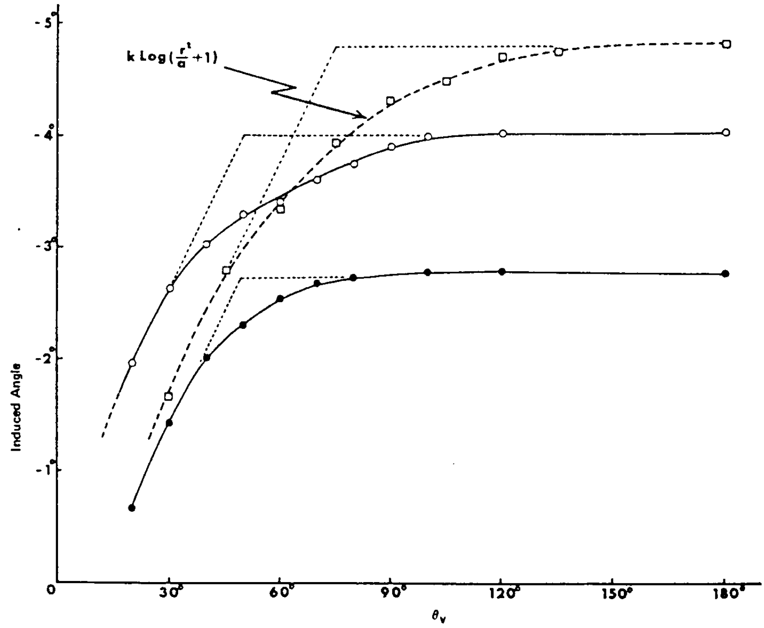

Fig. 8. Induced subjective coordinate axes tilt as a function of display image tilt; --□-- grating pattern, tilted −17°; --○-- suspension bridge; tilted −10°; --●-- open landscape, tilted −10°. Averaged from evaluations by four observers. θ_v is the viewing angle under which the display was observed.

Influence of a Wide-Field Display on the Observer's Head and Eye Movements

In observing a picture projected on a wide screen there exists little restriction, such as the restriction given by a picture frame, and the observer's condition is quite similar to that in daily life with regard to the perception of visual information. Even with accompanying auditory information, the visual information perceived on current home TV receivers obviously provides a lesser amount of information. But, by expanding the field of a visual display the amount of information may be made to approach the natural condition.

We have carried out measurements of the spontaneous eye and head movements used by the observer as active means for the perception of visual information in daily life. When one is looking at a given point within one's visual field and a new stimulus arises at another location distant from the original visual target point, one will shift one's gaze to the new stimulus point. One may do so either by a simple eye movement or by turning the head, depending on the magnitude of the angular distance that separates the new stimulus from the original target point. The results of these measurements are shown in Fig. 10.

The average tendency[7] permits two conditions to be formulated: (1) the range restricted to simple eye rotation movements is 30° horizontally, 8° upward, and 12° downward, which is quite small with regard to the total visual field; (2) the range of head movements for the search of information without too much observer strain is wider than that of the eye movement in condition (1), but when head movements surpass 90° horizontally, 15° upward, and 30° downward the observer will generally feel strain during head movement.

From these results we have concluded that the range within which an observer may conduct a fairly natural information search would have a narrower viewing angle than condition (2) above; but television provides at present a condition that is even narrower than condition (1) above. As a consequence, the current TV display is tiring to look at because it creates a condition of a fixed semi-stare.

Investigating the degree of use of the various sensory systems in daily life, we found that the rates of sensory use are approximately one unit for the auditory sensation, 500 units for the visual sense, and less than 1/100 unit for the sense of touch. Also, the capability for instantaneous in-

(a) (b)

Fig. 9. Pictures used in tilt angle induction experiments: (a) composition giving a feeling of depth; (b) composition giving a feeling of expanse.

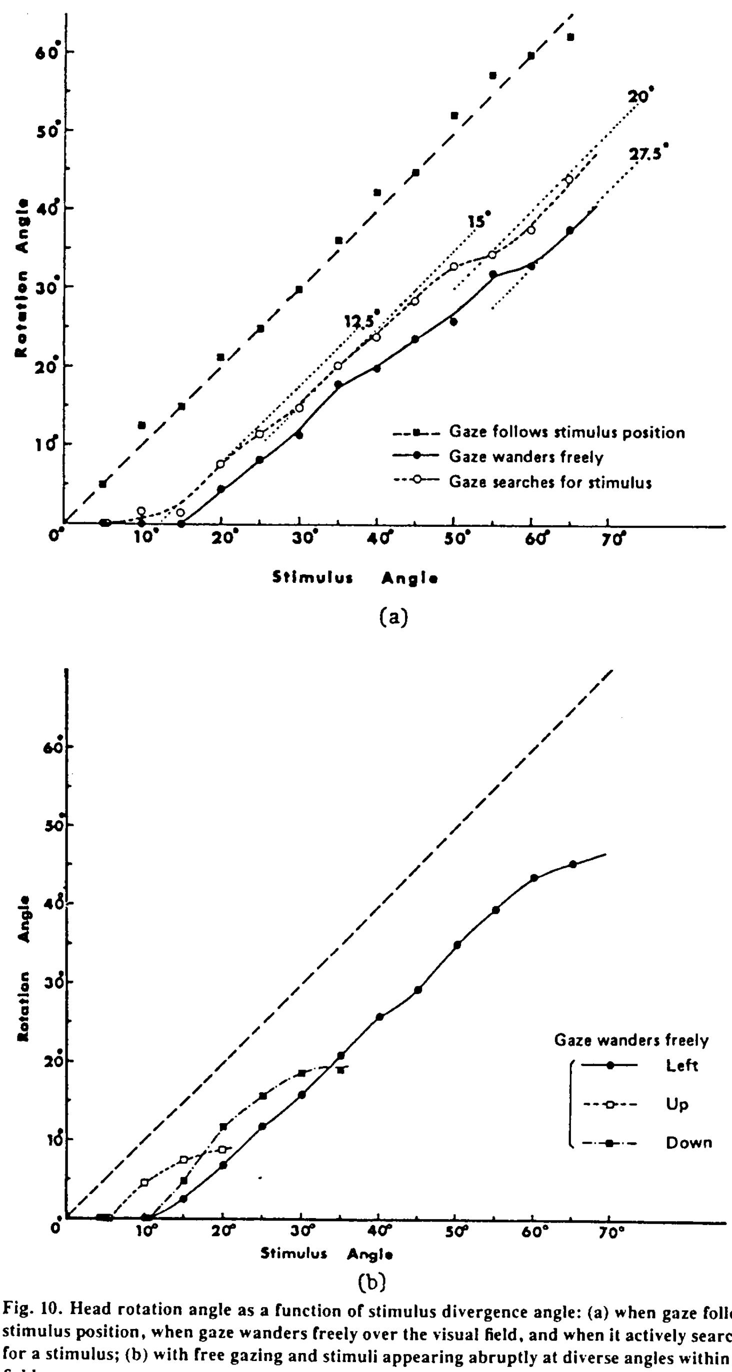

Fig. 10. Head rotation angle as a function of stimulus divergence angle: (a) when gaze follows stimulus position, when gaze wanders freely over the visual field, and when it actively searches for a stimulus; (b) with free gazing and stimuli appearing abruptly at diverse angles within the field.

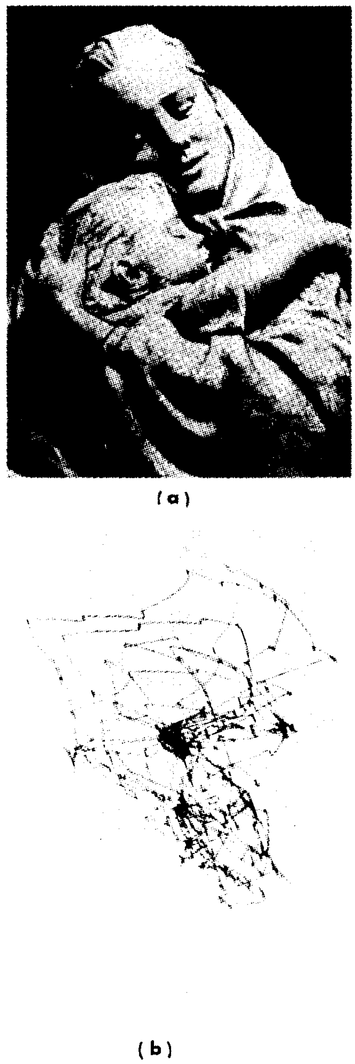

Fig. 11. Eye movements induced by a picture; (a) stimulus picture; (b) trace of gaze wandering over the picture during a 2-min observation period. Note that the eye concentrates on characteristic points within the picture, faces and hands of mother and child (from Yabus[9]).

formation processing is four bits per second, and this means that we are using only about 1/50,000 of all the information received through the various senses. It is difficult to determine to which type of information perceived through the senses we attach the most importance, but various experimental results show that visually perceived information is given high priority.

(Even if there is a discrepancy between the location of the sound source indicated in a picture display and that of the loudspeaker actually radiating the sound, the observer still will feel as if the sound were coming from the source shown in the picture. When this discrepancy becomes greater than 15°, some sensation of unnaturalness is felt, however.)

As far as information display is concerned, auditory information can easily be reproduced as three-dimensional (stereophonic) sound, but the display of visual information is considerably more restricted. It seems obvious that, in the near future, there will certainly be demands coming forth for wider displays of visual information. So far, our attention has mainly been directed toward the appraisal capacity of the displayed information. It is difficult to explain completely the psychological effects that are induced by the aspect ratio of the screen and by the distribution of the characteristic points within the picture composition if the explanations are based solely on the quantitative analysis of information. For instance, we can see (Fig. 11) that one's vision is concentrated on the main characteristic points in a picture.[9] But it would be difficult to determine what distribution of visual target points would be produced by a picture with a harmonious and beautiful composition. We are trying to find out what sort of change is seen in the visually evoked responses when the observer feels the beauty of an object, and we are also trying to discover a clue for the analysis of these responses.

Object Size within the Picture Display

Depending on the kind of information contained in a picture, especially the size of the photographed object, the observer may sometimes feel that this subjective distance to the displayed space segment is different from the real distance, and he may feel a very strong impact of the object and of the depth of space on his perception. One of the reasons that TV program directors are using more and more close-ups is that (apart from the inadequate resolving power of TV systems for long-shots) close-ups obtained with telephoto objectives have a great impressive force that makes viewers feel as if they are being "pulled" toward the scene on the screen. To check these psychological effects we have conducted a psychological experiment using a subjective evaluation method under conditions where the viewing distance and projection magnification can easily be changed with a setup such as shown in Fig. 2. The following is a summary report on the experiment.

Experimental setup. Subjective evaluation was carried out with a setup where the projection distance (L_p in Fig. 2) could be changed, thereby altering the display magnification, L_p/L_f. Also, the retinal image magnification, $\theta_v/\theta_p = (\theta'_v/\theta_p) \cdot (\theta_v/\theta'_p)$, can be altered through simply changing the observer's viewing distance (L_v in Fig. 2). In this experiment, the same pictures as in Fig. 9 were used, and the projected image is in the form of a circular display on the screen as in the earlier experiment illustrated in Fig. 7

Subjective evaluation method. The concept to be evaluated is the "sensation of reality" felt by the observer on the basis of the overall impression of the psychological effects (space fusion, feeling of expanse, naturalness, feeling of depth, impressive powerfulness) summarized in Fig. 3. The subject is first shown for 15 s a picture under conditions that are to be used as a comparison standard.

(A picture having a camera angle of 25° is projected on a screen from a distance of 4.5 m so that the display area of the projected picture will be 1.5 m²; the horizontal viewing angle will then be 38° when the displayed picture is observed from a distance of 2 m (Ref. 6). This corresponds to about the same conditions as when viewing a CinemaScope screen from a seat at the center of the theater auditorium.)

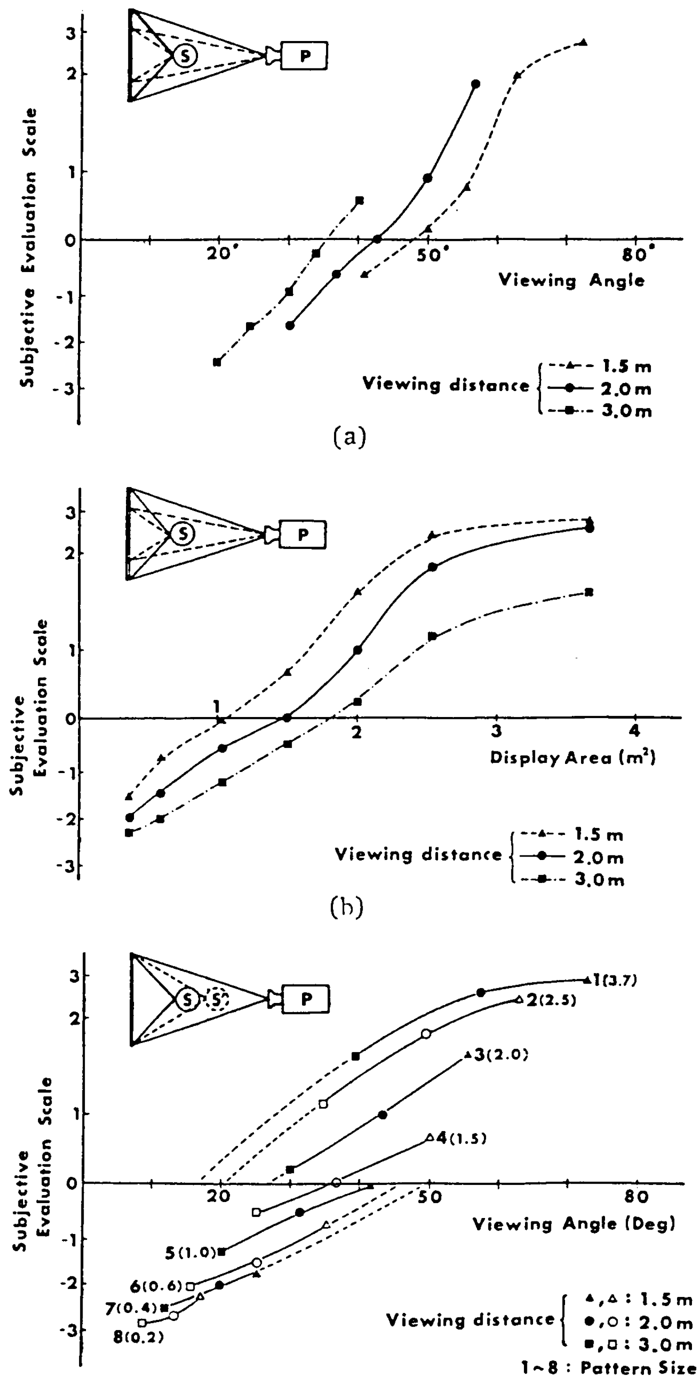

Fig. 12. Measurement of the "sensation of reality effect": (a) when changing the viewing angle; (b) when varying the display area; (c) when varying the observer distance. Average results for five observers. Numbers in parentheses show display area in m².

Evaluation tests were then conducted on a subjective seven-step scale, comparing the standard display with the test pictures under various changed viewing and projection distances (Figs. 12 and 13).

Experimental Results on Displayed Object Size

The following is a summary of the experimental results obtained by varying first the viewing angle, and after that the dis-

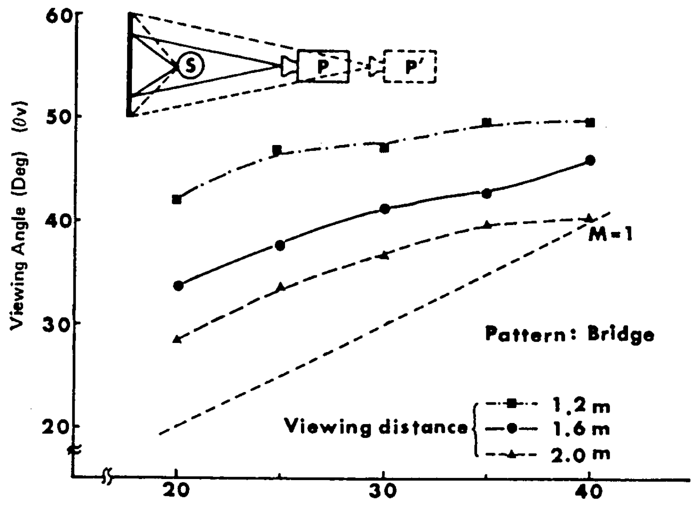

Fig. 13. Viewing (retinal image) magnification, θ_v/θ_p, at which the observer begins to have a sensation of reality. Projection magnification was varied while maintaining a given observer distance. The upper part of each curve relates to the sensation-of-reality effect. The dashed line indicates a viewing (retinal image) magnification equal to unity.

play area, the viewing distance, and the viewing (retinal image) magnification.

Effects of changes in viewing angle. Figure 12a illustrates the results obtained by changing the projection angle θ'_p, while maintaining the viewing distance L_v constant, thus changing the viewing angle. The following results were observed.

1. The sensation of reality increased in proportion to the viewing angle and did show a tendency toward saturation when the viewing angle exceeded 60°. These results are similar to those of the earlier described subjective coordinate axes induction experiments.

2. If the viewing angle is fixed, the effect will be stronger when the display area is large and the viewing distance is long, i.e. when lateral projection magnification and viewing distance increase by the same factor.

3. To obtain an effect equal to the standard condition described, a viewing angle of 15–20° will be necessary with a wider camera angle, and a viewing angle of more than 45–50° will be necessary with a narrower camera angle.

Effects of changes in display area. This is illustrated by Figs. 12b and c, with the results described as follows.

1. With a display area of 2.5 m^2 or more (and a camera angle of about 40°) the effect will show a tendency toward saturation.

2. To obtain an effect similar in strength to the standard condition with a display area of less than 1 m^2, a viewing angle of at least 40° will be necessary.

With regard to Fig. 12c the following comments should be taken into account. This figure shows the result of an experiment in which a series of eight successively greater display areas were used. For each display area three observer distances were used, so that a series of three different viewing angles were obtained for each given display area. In this fashion the results of this experiment can be applied to yield conclusions on the influence of the area of the display on the observer, as well as with regard to the influence of the viewing distance on the observer. The latter parameter (distance variation) is referred to in the next section. The relation among the parameters "display area," "observer distance," and "viewing angle," illustrated in Fig. 12c, are detailed in Table II. A display with a circular frame was used for this series of experimental evaluations. Each observer was asked to give his rating on the seven-step scale for each of the resulting 24 configurations.

Effects of changes in viewing (observer) distance. (See Figs. 12 and 13.) Apart from the results shown in Fig. 12, we conducted tests to find out at which viewing distance one begins to have a sensation of reality (Fig. 13), and found the following.

1. While it is possible to obtain a good result by shortening the viewing distance and increasing the viewing angle and viewing (retinal image) magnification, a viewing distance shorter than 1 m should be avoided.

2. The viewing distance at which one begins to have a sensation of reality is related to the distance at which one is able to see a characteristic object within the picture at a certain viewing angle, rather than to the viewing angle of the display picture as a whole. However, with a viewing angle narrower than 40°, there is a tendency for the characteristic object to be perceived by the observer as being somewhat larger than it really is.

Table II. Viewing angles as a function of display area diameter and observer distance when using a circular display.

Display area in m^2	Display diameter in m	Viewing angle θ_v in degrees as a function of three observer distances L_v in m		
		3 m	2 m	1.5 m
3.7	2.17	40	57	72
2.5	1.98	33	48	61
2.0	1.60	30	44	56
1.5	1.38	26	38	49
1.0	1.13	21	32	41
0.6	0.87	17	25	32
0.4	0.71	14	20	27
0.2	0.50	10	14	19

Effects of changes in viewing (retinal image) magnification, θ_v/θ_p. As shown in Fig. 13, we have tried to find the minimum viewing angle at which one begins to experience a sensation of reality. This was investigated by varying the display magnification, L_p/L_f, of pictures taken with different camera angles. Below follows a summary of our findings.

1. When the viewing magnification was increased, the impact of the sensation of reality was felt more strongly.

2. The observer tended to try and see the picture at a larger viewing (retinal image) magnification when the picture had been photographed with a narrower camera angle, or to view such a picture from a shorter distance.

3. Depending on the content of the picture (for instance, a picture containing a human figure, or one that enables the observer to estimate the camera distance at which the objective had been photographed), the observer tried to view the picture at a distance where its content appeared to him at a natural size.

Conclusions

In this discussion we have outlined the results obtained from our psychophysical experiments on the psychological effects exerted on the observer by visual wide-field picture displays. These experiments were conducted mainly pointing toward future innovations in TV technology, when high-definition TV displays and three-dimensional image viewing will become reality. We did not touch on the sharpness of the TV image, which is closely related to high-definition technology. Our experiments were restricted to exploring picture display dimensions and viewing conditions. However, we believe that we have succeeded in some measure in establishing basic observer tendencies.

In particular, we believe that our experiments have succeeded in paving the way for the quantification of the psychological effects under which a strong emotional feeling such as the sensation of reality is evoked. We also believe that our experiments have provided us with usable data with regard to the functions of the visual field (Fig. 14).

The discriminatory visual field. It extends throughout the range within which the observer has high-precision discriminatory capability and perceives detailed information accurately, with a visual acuity of over 0.5. This is an area of about 3° from the fovea.

The effective visual field. Within its range, the visual acuity falls to about 0.1, but discrimination of a simple figure can be accomplished in a short period of time.[10] This is the range within which an observer looks naturally at an object without head movement and is able to process effectively the information perceived. It extends to maximal values of 30° horizontally, 8° upward, and 12° downward.

The induced visual field. This includes the range within which the observer has discriminatory capability to the extent of being able to recognize the existence of a visual stimulus; but this range is related to the observer's posture judgement in regard to information available in his surround space. It covers 20–100° horizontally, and 20–85° vertically.

The supplementary visual field. This is a range which has no direct functional role in the perception of visual information; but it has a supplementary function to the extent that it can arouse a shift of the observer's gaze in response to abrupt stimuli. It covers 100–200° horizontally, and 85–125° vertically.

With a visual field having the described characteristics and being complemented by active eye and head movements, the human observer has at his disposition a cleverly designed system for the perception of visual information from a wide field of vision. A display that adjusts itself to these characteristics will become the method for faithful reproduction of spatial information in the true sense of the word. Also, results of our subjective evaluation experiments show that the information that influences the observer's subjective viewing distance will sometimes be a "natural" display within a picture and at other times it becomes the factor that produces a picture of strong impact. While — in the opinion of some — such effects appear, under the influence of close-up scenes, in TV programs and motion pictures, the experiment has shown that such scenes constitute an effective method for producing in the viewer a feeling of entering right into the displayed space, even in the small display size as we know it at present. In particular, experiments using simple moving pictures confirm that this method is more effective in the display of moving images.

As can be seen from the foregoing, we have limited ourselves to research about the basic characteristics because our experiments were conducted under restricted conditions. However, in the future, we intend to set up an experimental environment closer to existing picture display conditions and to use the results of these experiments for the study of observer reactions (such as, for example, the change in posture) to quantify the psychological effects by an objective method, and to study at the same time the factors that produce such psychological effects.

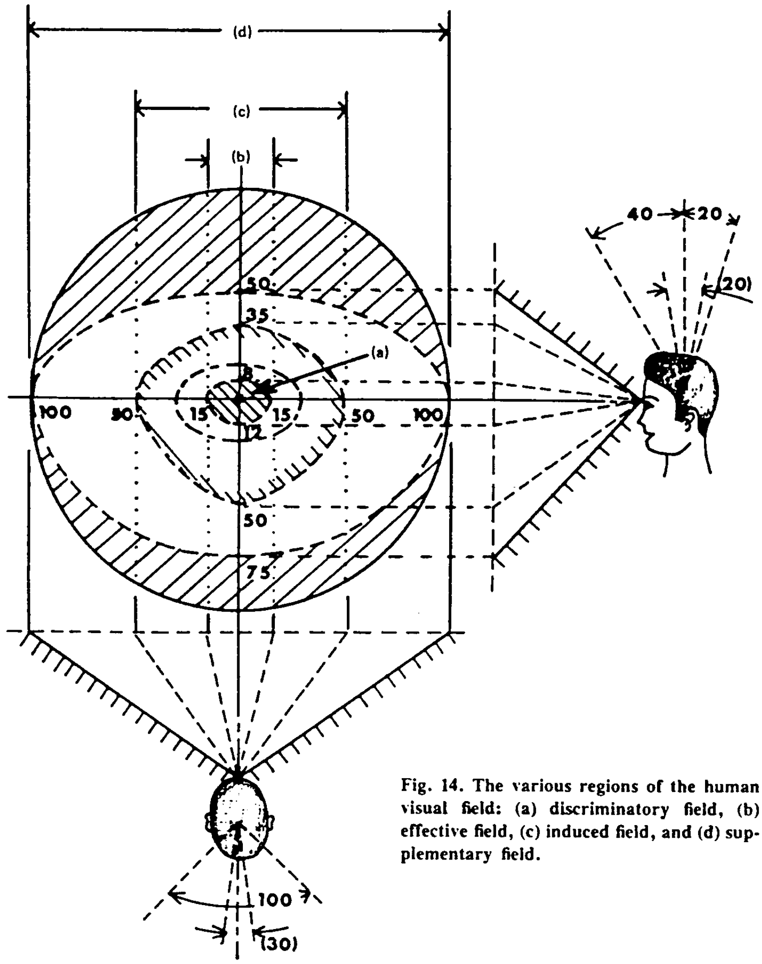

Fig. 14. The various regions of the human visual field: (a) discriminatory field, (b) effective field, (c) induced field, and (d) supplementary field.

Acknowledgment

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