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INTEGRATING TIME FOR VISUAL PATTERN PERCEPTION AND A COMPARISON WITH THE TACTILE MODE

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Abstract—A display system to present a pattern element-by-element was constructed and the integrating time-period to ensure normal visual pattern perception was investigated. A cartoon-type picture was divided into 10 × 10 or 5 × 5 portions which were successively presented to the subjects at various time-intervals. The impression of having a "visual image" of the picture (i.e. that the stimulus display appeared to the subject as a coordinated figure) was used as the criterion for normal pattern perception. The average integrating time was found to be about 500 msec. When the presentation of the entire stimulus pattern was prolonged, the subject could no longer perceive a normal visual image. These perceptions were compared with perceptions observable for tactile sensations and the similarity between them were demonstrated. The terms "motor image" and "logical image" were used to define these perceptions.

INTRODUCTION

The human visual system is equipped with a very wide visual field, primarily due to the round shape of the eye and to the retina's stretching over almost the entire area of its inner surface. One advantage of having such a large field is obviously the superior ability to detect incoming information for a wide range of stimuli whether they be static or moving objects. Although it may not be immediately obvious there is another important advantage; that is, that information which is spatially distributed over a wide area can impinge simultaneously upon the retina. The importance of this phenomenon has been shown experimentally by artificially narrowing the visual field. With a narrowed visual field scanning of the stimulus pattern becomes necessary and, thus, the input becomes sequential. One consequence of this is a serious deterioration in pattern perception (Becker, 1935; Yamane, 1935; Watanabe, 1971; Ikeda, Saida and Sugiyama, 1977).

However, it is quite certain that a truly simultaneous presentation of the constituent elements of a pattern is indeed unnecessary. Many visual phenomena indicate the existence of a certain time-period within which the incoming visual information is integrated or stored. Two such examples are Bloch's Law, observed in threshold experiments, and the concept of visual information storage, exhibited in partial report experiments (Sperling, 1963). Therefore, it is natural to consider such an integrating time-period to exist in the case of pattern perception, and, indeed, several investigations have reported such findings. For example, Haber and Standing (1969) determined the speed with which a slit must move back and forth over a geometrical stimulus pattern, such as a circle, in order to produce a continuous perception of that pattern. This value was 320 msec with a bright stimulus of 150 cd/m^2, and 340 msec with a dim stimulus of 1.5 cd/m^2 for one scanning. Hogben and Di Lollo (1974) concluded the integrative time to be about 120–140 msec. They presented the subjects with 24 dots, arranged in a 5 × 5 matrix, in succession, and asked them to detect the one dot that was missing from the 25 dot places. Eriksen and his colleagues employed two stimuli, which were nonsense figures by themselves, but became meaningful letters or patterns if presented together one over another. They obtained a value of about 80 msec at a 50% correct response level in the case of letters, and about 150 msec in the case of patterns (Eriksen and Collins, 1967; Rohrbaugh and Eriksen, 1975). McFarland's method (1965) was to use an equilateral triangle as the stimulus and to present its sides in succession. The subjects could perceive these three sides simultaneously, but not necessarily in the correct spatial relationship, when the entire stimulus was exposed within 112 msec. Lichtenstein (1961) asked subjects to judge the subjective simultaneity for four light spots arranged at corners of a diamond, and presented them in succession with a varying total duration. The impression of simultaneity was observed at durations up to 125 msec.

All these experiments indicate the existence of an integrating time-period for pattern perception, and the above evidence indicates that it does not extend beyond 340 msec. However, the patterns employed by these authors were limited to geometrical figures, light spots, or letters. No ordinary figures such as objects, portraits or scenes have been used at all. Before accepting these authors' values as the general integrating time-period for visual information processing, it seems necessary to test more general patterns. The manner of presenting the stimuli has also been relatively simple in the previous authors, except Hogben and Di Lollo's dots presentation method, such as to divide a stimulus into two or three of its main parts. Our experiment aims to present them divided more than simply into halves or thirds.

For this study a more generalized element presen-

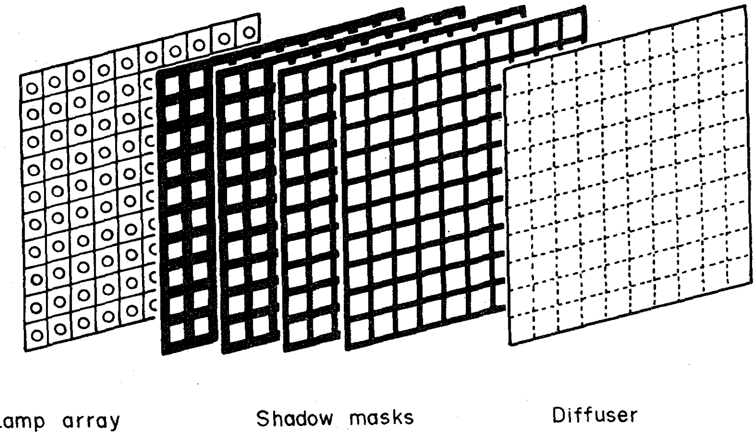

Fig. 1. The display unit for the element presentation method.

tation method was developed in which any figure can be presented part by part with any desired time-interval between these parts. Using this method, the limits of the integration time for pattern perception were investigated.

The present report consists of three parts. The first is a preliminary experiment to introduce the criterion, "visual image". In order to determine the integrative time-period, a new criterion was used—that of a "visual image"—rather than the criteria such as "simultaneity", "continuity" or letter detection used by previous authors. Here, the temporal interval between presentation of the elements was extremely long. This experiment will be only briefly explained. The second is the main experiment of this report. The interval between elements was much smaller and the integrative time-period for pattern perception was established. The third is a supplemental investigation in which no stimulus figure was used but only illuminating patches.

EXPERIMENT I. SLOW ELEMENT PRESENTATION

The method employed to present a pattern to the subject was to illuminate it part-by-part from behind. The display unit designed to do this is shown schematically in Fig. 1. 100 small filament lamps were arranged in a matrix form of 10×10 on a lamp array. At the other end of the display unit a diffuser (i.e. a rear projection screen) of 25×25 cm was located. Between the lamp array and the diffuser, several shadow masks were placed so that any one lamp illuminated only a corresponding small square region on the diffuser without causing any overlap to the neighbouring sections. The luminance at the diffuser, when lit, was $1.6\,cd/m^2$. Black stimulus patterns were drawn on transparent plastic sheets which were attached to the diffuser screen. The subject observed the stimulus binocularly from a distance of 1 m. The subject was provided with a switch panel in front of him, which had 100 switch buttons arranged in a matrix form of 10×10, exactly corresponding to the matrix of the divisions on the diffuser. By touching lightly any one of the buttons, the subject could illuminate the corresponding square region on the diffuser and thus a corresponding element of the stimulus pattern. The illumination continued for as long as the subject pressed the button.

An example of a stimulus pattern is shown in Fig. 2, with cross stripes to show the size of the sections illuminated by the switch buttons. The figure was taken from an ordinary magazine and is a familiar picture to Japanese subjects. All patterns used in the experiment were cartoons taken from various Japanese magazines, and consisted of a human figure engaged in some action. Subjects were asked to observe the stimulus by illuminating its elements one after another until they could tell "what is doing what" in the picture. Thus, the response to the example shown in Fig. 2 would be "a boy running hard". Subjects were not allowed to illuminate two or more elements at any one time, but they could observe any element more than once and for any duration.

The task was found not too difficult for most of the subjects and for most of the stimulus patterns,

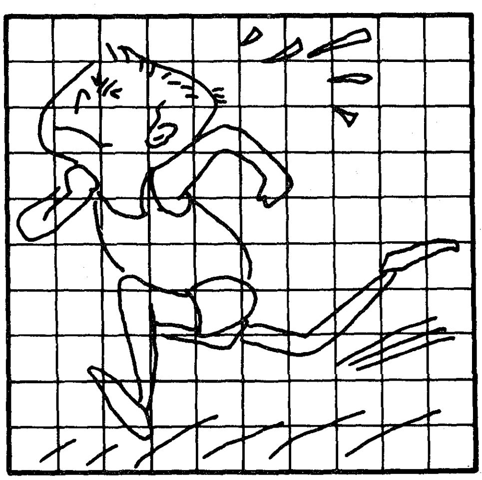

Fig. 2. An example of displayed patterns. Cross stripes show the size of the illuminated sections.

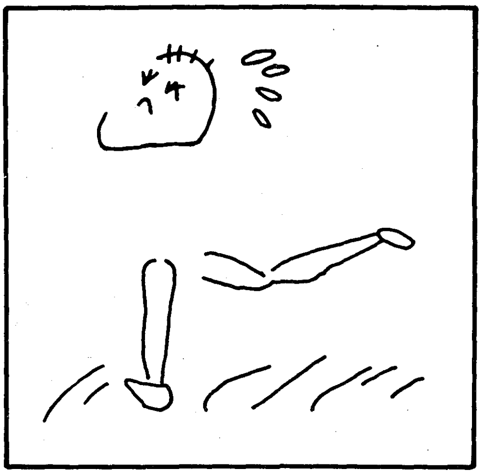

Fig. 3. A drawing by a subject after observing the stimulus of Fig. 2.

An extreme case which shows the importance to pattern perception of having a visual image is given in Fig. 3. One subject was unable to construct even a logical image after observing the stimulus shown in Fig. 2 for a period of about 5 min (i.e. he could not reach any meaningful figure by himself). So he was asked to draw a picture afterwards from memory. His drawing is reproduced in Fig. 3. This is a fair approximation to the original figure, yet he had been able to construct neither a logical image nor a visual image. We might call an image such as this subject had of this stimulus, a "motor image", because it only provided enough information to reconstruct the pattern by the motor system. Surprisingly, however, once the subject saw in full the picture that he had drawn, he was immediately able to understand it. It thus seems that a visual image is indispensable for normal visual pattern perception. Furthermore, as indicated above, it seems that such a visual image is obtainable only for rapid presentations of the elements.

although the duration of the total observation time varied greatly among the subjects as well as the patterns. A very interesting phenomenon became evident from the experiment. Subjects were able to respond to the stimulus pattern with the right answer most of the time, such as "a boy running hard". However, when figures were shown in full, afterward, subjects often said that the figures looked quite different from images they gained through the element presentation method. That is, each element from the original pattern was usually present in the subject's image, but they were not necessarily coordinated properly to form the pattern which had been shown. This seems to indicate that, in spite of correct verbal responses, subjects were unable to construct an exact image through the slow presentation method. They seem to have constructed the images "logically", so to speak, by using the shapes and positions of the elements given on the display screen. Such an image may be called a "logical image" while an image constructed through normal visual perception may be called a "visual image".

EXPERIMENT II. FAST ELEMENT PRESENTATION

Apparatus

To obtain a fast presentation of the elements, the manual operation of lamp illumination was abandoned and the operating switches were replaced by an electronically controlled unit. A pulse generator determined the duration of illumination of each element and it was set to $D = 200$ msec throughout (Fig. 4). An oscillator provided the interval, I, between any two successive elements (i.e. the element onset asynchrony). I was readily changed by manipulating the oscillator. The number of elements was reduced to 5×5 (i.e. 25) as indicated by the cross stripes on a sample pattern in Fig. 4. The total duration for presentation of the whole pattern was defined as T, which was equal to $I \times 24$. Each element was illuminated only once and the illumination was made in a random order. The order could be changed manually by rewiring connections between the lamps and the electronically controlled unit. The work was, however, very time consuming and the order was kept constant throughout the experiment.

Stimulus patterns were taken from the *New Golden Dictionary* (edited by Parker and Battaglia), Golden Press (1974), and each consisted of a human figure doing some

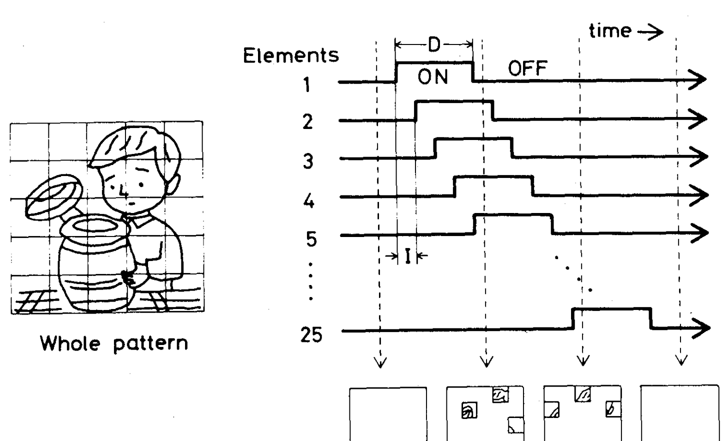

Fig. 4. An example of displayed patterns (left). Time conditions for presenting a pattern (right). D: duration of each element. I: element onset asynchrony. Pictures at the bottom on the right-hand side show examples of display at various moments.

Fig. 5. Four examples of displayed patterns.

action. One example was already shown in Fig. 4 and some others are shown in Fig. 5. Stimuli were printed as negative transparencies on 12.5 × 12.5 cm square sheets of film. Thus, when the stimuli were presented on the display screen in a dark room, only the lines appeared bright, and their width was 2 mm wide, with a luminance of 1.47 cd/m^2. Subjects viewed the stimulus binocularly from a distance of 1 m with a chin rest. Each side of the stimulus subtended a visual angle of about 7°, and each of the 25 elements subtended about 1.4°.

Subjects

Five experienced male and four naive female subjects were tested.

Procedure

As a preliminary session, a few stimuli were shown to each subject at random intervals of I = 0, 5, 10, 20, 40 or 100 msec. Each of the various intervals (I) were tried and the subject was asked for each interval if the displayed pattern looked like one meaningful and coordinated figure. If the subject responded affirmatively, he was told that he had arrived at a *visual image* of the stimulus. It was not simply a uniformity of the pattern but a coordination as a single figure that the subject was told to define as the visual image. The subject was not particularly requested to grasp the details of the figures. Within several trials, each subject was able to respond "yes" or "no" for the construction of a visual image, for any stimulus pattern or for any interval.

Five different intervals were investigated. They were: I = 5, 10, 20, 40 and 100 msec; or T = 120, 240, 480, 960 and 2400 msec, respectively. For each total duration T, twenty different stimulus patterns were prepared for the experienced subjects and eight different stimuli for the naive subjects, with a total, therefore, of either one hundred or forty different patterns for each subject. No stimulus was used twice with any one subject, to avoid a learning effect. Settings of T were randomized and the entire set of stimuli was presented in a single session for each subject.

Upon the establishment of the criterion of "yes" and "no" for the visual image the main experimental session started. The exposure of a stimulus pattern was initiated with a starting key pressed by the subject himself whenever he was ready. Immediately after each exposure the subject responded verbally with "yes" or "no". No fixation point was used and the subject was free to move his eyes during the stimulus exposure period.

Results

The percentage of "yes" response are plotted against the total duration T for experienced subjects in Fig. 6a, and for naive subjects in Fig. 6b. All subjects expressed the impression of having a visual image for all stimulus patterns at the shortest total duration employed, namely T = 120 msec. For longer durations they began to fail to perceive the visual image. Instead, the stimuli were seen as incomplete patterns or just independent assemblies of elements. At T = 2400 msec *no* stimulus pattern appeared as a coordinated figure. They appeared only as successive elements having no apparent interrelationships.

The threshold for the construction of a visual image may be defined for each subject by the T value at which that subject could successfully construct a visual image only 50% of the time (i.e. only 50% "yes" responses). These T values are summarized in Table 1 for experienced subjects as well as for naive subjects. In general the threshold value for the experienced subjects appears longer than that for the naive subjects, a mean value of 597 msec being observed for the former and 407 msec for the latter. The mean across all subjects is 504 msec.

EXPERIMENT III. BRIGHT PATCH PRESENTATION

This experiment only differs from Experiment II in the test stimuli. No figures were used and subjects

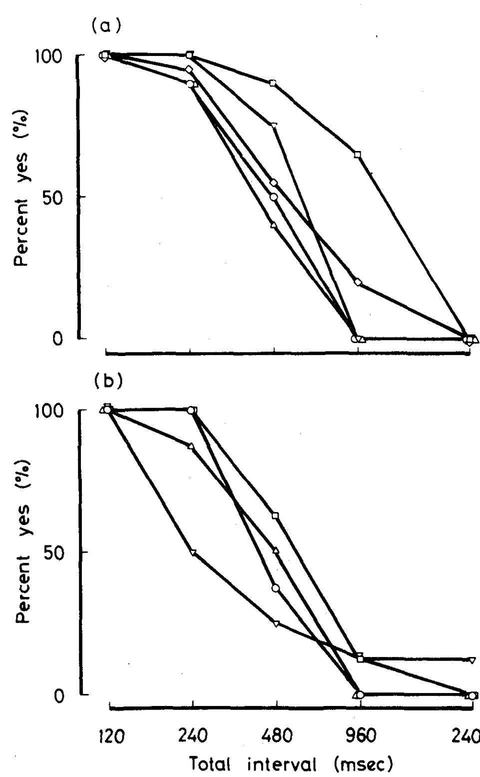

Fig. 6. Percentage of "yes" responses vs total interval T for figure patterns. (a) Experienced subjects; □: YN, ▽: TG, ◇: MI, ○: KS, △: MO. (b) Naive subjects; ○: YI, □: KK, △: KH, ▽: YK.

Table 1. Thresholds for the visual image for figure patterns, defined by the T value at the 50% yes response (units in msec)

Subject		Threshold
Experienced:	YN	1186
	TG	605
	MI	530
	KS	480
	MO	418
	Mean	597
Naive:	KK	571
	KH	480
	YI	418
	YK	240
	Mean	407
Mean (all subjects)		504

saw the display screen directly, where illuminated square patches of 1.4° × 1.4 arc of visual angle appeared successively. The instructions to the subjects were the same as those of Experiment II, namely to respond "yes" when all these patches appeared to resemble a coordinated large square of 7° × 7° arc of visual angle. It was not necessarily the construction of a large square uniform in brightness, but rather the coordination of the elements into a single spatial pattern corresponding to one large square, that the subjects were asked to set as a criterion for the "yes" response.

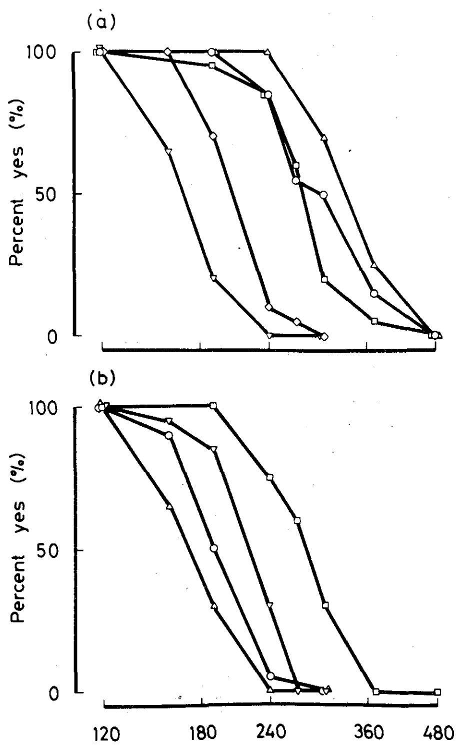

Fig. 7. Percentage of "yes" responses vs total interval T for illuminating patches. (a) Experienced subjects: ○: MI, □: MO, △: SR, ◇: TK, ▽: HY. (b) Naive subjects: □: JM, ▽: HA, ○: MK, △: YT.

Five experienced male and four naive female subjects were employed. Two of the subjects had participated in Experiment II previously. Total intervals employed were: $T = 120$, 160, 192, 240, 267, 300, 369 and 400 msec.

Results are shown in Fig. 7a and b for the experienced subjects and the naive subjects, respectively. Each point was obtained from twenty observations. All subjects gave 100% "yes" responses at $T = 120$ msec. However, upon increasing T, each subject soon began to fail to perceive the elements as one united group, and at $T = 480$ msec no subject gave a "yes" response. The threshold for 50% "yes" responses for each subject is shown in Table 2. The mean threshold is only 231 msec, and this is much shorter than the value for patterned stimuli in Experiment II.

DISCUSSION

Normal visual perception was considered to have occurred if a *visual image* was constructed by the subject. The mean integrating time for the image was about 500 msec when stimulus patterns were cartoon-type pictures (Table 1) and about 230 msec when the stimulus was an assembly of small bright squares (Table 2). Subjects MO and MI participated both in Experiments II and III, and clearly showed the tendency of longer integrating time for the image of a cartoon-type picture than an assembly of squares. If we can assume, as the subjects reported later, that they kept the same criterion for the construction of the visual image in both experiments, we may conclude that our visual system is able to integrate patterns which are presented over a longer period of time when they have meaning.

The integrating times found in these studies are a little longer than the integrating times cited by other authors (e.g. Lichtenstein, 1961; McFarland, 1965). The differences may partly stem from different criteria having been used to determine the integrating time. The criteria adopted by previous authors, such as an impression of simultaneity or uniformity, may be too conservative as a measure of normal visual pattern perception. Patterns can be perceived accurately without having an impression of simultaneity or of uniformity. Therefore, the criterion of constructing a visual

Table 2. Thresholds for the visual image for illuminating patches, defined by the T value at the 50% yes response (units in msec)

Subject		Threshold
Experienced:	SR	328
	MI	300
	MO	274
	TK	207
	HY	170
	Mean	248
Naive:	JM	277
	HA	221
	MK	192
	YT	173
	Mean	212
Mean (all subjects)		231

image may be a better criterion for measuring visual perception. In the present experiments the order of presenting picture elements was kept constant throughout. We asked the subjects if they noticed the constant sequence of the presentation. Answers were all negative and we felt it was immaterial to alter the random order anew on each trial in determining the integrating time.

Several other phenomena have become evident through the experiments with the element presentation method. We used the term "image" to specify the state of the visual system in regard to pattern perception. It was found that there were three different types of images obtainable by observing a pattern whose elements were presented successively. These are:

The motor image: For this image there is enough information to reconstruct the pattern by drawing it on paper, but the subject is unable to construct cognitively any meaningful coordination of the elements. This image is obtained when the elements are fed into the visual system in very slow succession.

The logical image: For this image there is enough information to arrive at a cognitively meaningful coordination of the elements, but the resulting image is quite different from the actual pattern. As with the motor image, this image is obtained when the elements of the pattern are fed into the visual system in very slow succession.

The visual image: This image corresponds to the original pattern and ensures normal visual pattern perception. This image is obtained when the entire figure is fed into the visual system within a relatively short duration, such as 500 msec.

Becker (1935) and Yamane (1935) pointed out that a similarity existed between visual and tactile pattern

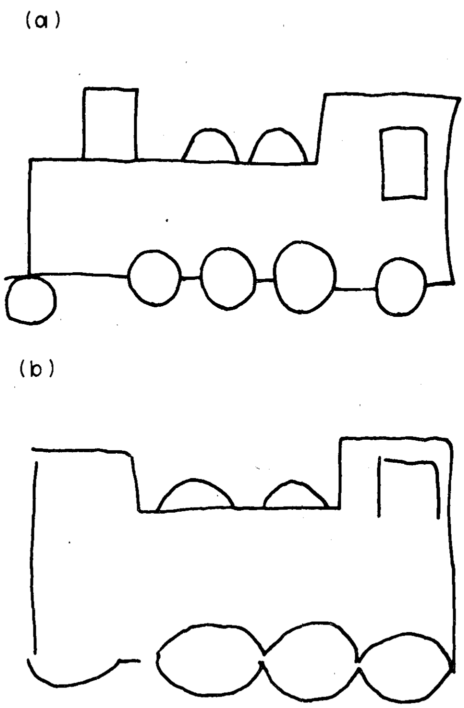

Fig. 8. (a) A stimulus pattern used for tactile perception. (b) A drawing after observation. Subject MI.

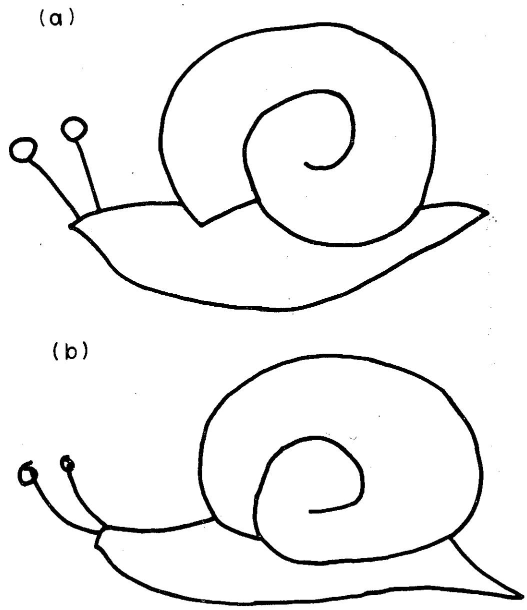

Fig. 9. (a) A stimulus pattern used for tactile perception. (b) A drawing after observation. Subject MI.

perceptions when the former was achieved through a small hole which inevitably prolonged the inputting time of a whole pattern into the visual system. Such a situation can be demonstrated here as a similarity between the motor or logical image and the perception obtained through tactile sensation. For example, we presented a subject with a picture shown in Fig. 8a which was drawn on a soft plastic sheet called the raised writer with a ball point pen so that the subject could feel the picture with his fingers. His eyes were closed and he was asked to try to perceive the pattern through tactile sensation only. He spent about 5 min tracing the picture with his fingers, but finally exclaimed that he had no idea whatsoever what was on the sheet. He was, however, able to draw what he remembered on paper with his eyes open. His figure is reproduced in Fig. 8b. As soon as he saw the picture that he drew, he recognized it as a locomotive. This is exactly the same phenomenon observed with the motor image in the element presentation experiment. It seems, then, that the motor image might be built and stored at the same level as tactile image in spite of the fact that the motor image was constructed through the visual system.

Fig. 9b is another example of a picture drawn by the same subject after a 5 min tactile examination of the raised writer shown in Fig. 9a. From this drawing, there is little question what the stimulus represented. With only the tactile sensations, however, the subject reported that the pattern might be either a hat or a snail. He came to this conclusion according to his logical analysis of the information he obtained, that is, a large round bonnet, a broad brim, and two attached ornaments would make a hat; or scrollwork, a body and two antennae would make a snail. But he could not narrow down his answer to one single item. This situation is quite similar to the one in which the logical image was obtained through the visual system.

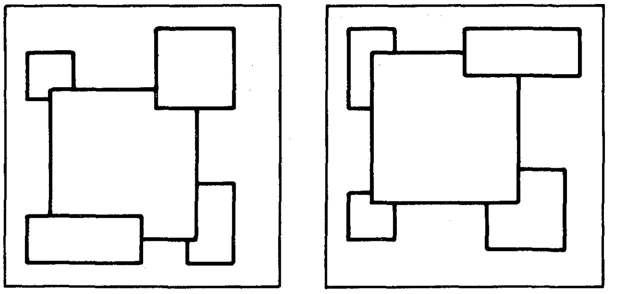

Fig. 10. Two examples of overlap-figures.

These two examples imply that information ingested through the visual system by a succession of its elements (that is, a motor or a logical image) may be very similar to an image which results from ingestion through the tactile system. This, indeed, is quite reasonable since the sequential nature of both types of input appears to be very similar.

The present experiment employed "the coordinated figure" as the criterion for the visual image. One might point out that the criterion is too phenomenological to know the actual criterion level that the subjects are exactly employing. It would be desirable, therefore, to replace the present criterion with some other specific criteria that would ensure the objective evaluation by experimenters. The criteria employed by Hogben and Di Lollo (1974), and Eriksen and his colleagues (Eriksen and Collins, 1967; Rohrbaugh and Eriksen, 1975), namely, the identification method of a dot or figures, might be modified to fit the present experiment. We have tried two methods to search such criteria within the realm of the element presentation method.

Immediately following the presentation of a pattern element by element, the subject was shown five pictures successively including that pattern with a help of a rapid projection system. He was asked to point out the picture that was presented previously by pressing a button. The hypothesis was that if the subject had gained the visual image, he could correctly discriminate the pattern shown previously from four other different pictures. The method, however, failed because he could almost always give the correct response regardless the total duration value T. He only needed to pick up any one cue in the picture to provide the correct answer, such as a portion of the flower in the case of the upper left stimulus in Fig. 5. He did not require the pattern perception of the entire picture. The other method was to present overlap-figures such as shown in Fig. 10. The subject was asked which rectangulars were above the central large square. The correct answer would be "the upper right and the lower left" and "the upper right" for the examples shown in Fig. 10, respectively. The hypothesis here was that the visual image would provide correct response. The method again failed because of the similar reason to the previous method as the subject was able to find out the answer merely by observing corners of the central square.

At present, therefore, we should be content with the criterion employed here in this paper, although obviously an appropriate criterion which would yield a more objective analysis in pattern perception should be searched for.

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system. These targets, however, do not appear in a clear open space but in most cases in the midst of other miscellaneous objects such as posters, signboards, and neon signs, which may be called the background noise if we are not interested in them. The task of the visual system is to detect targets by distinguishing them from the background noise.

Several authors investigated the functional visual fields when the eyes were engaged in such a task [2–6] and showed that the field size greatly decreased and also depended on the experimental conditions such as the target-noise difference, noise density and the duration of stimulus presentation. The field was called by Engel the *conspicuity visual field*. The conspicuity field was further modified by presenting a foveal load [7], i.e. the subjects were asked to detect a peripherally presented target as well as a figure presented foveally. Subjects were forced to pay attention to the central field rather than to merely fixate there. This naturally shrunk the field further. We called the field the *working conspicuity visual field* as it was obtained under a situation closer to everyday life than the conspicuity field.

In all the above investigations, subjects fixated their eyes on the central field when the stimulus was presented. That is, the subjects were not allowed voluntary eye movements. Their eyes were in a static state. Therefore, we use a generic name, the *static functional visual field*. Figure 1 summarizes the static functional visual fields

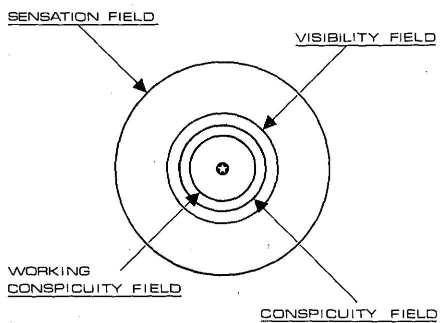

Figure 1. Schematic diagram showing the relative size of various static functional visual fields.

discussed above. A central point denotes the fixation point. The actual sizes of these fields may greatly depend on the experimental conditions and the scale in the figure is highly schematic. Further, there should be still some other types of visual fields in this category and a thorough and systematic investigation must be carried out.

2. Dynamic functional visual field

Let us proceed to another, quite different, kind of functional visual field. An advantage of the round human eye is its facility to rotate, which eventually appears as the eye movement. Figure 2 is an old Japanese poem drawn by a brush. When we read this, our visual axis scans the poem starting from the upper right corner, moving downwards, and finishing at the left, as shown by the eye movement trace. We notice here that the eye movement is composed of two features, namely fixations and saccades. The former last for about 250 ms and the latter only for about 25 ms. At the instance of the saccadic movement, therefore, the image of the poem should be moving very rapidly over the retina and no detailed information of the poem can be input into the visual nervous system, which was confirmed in part by the increase of

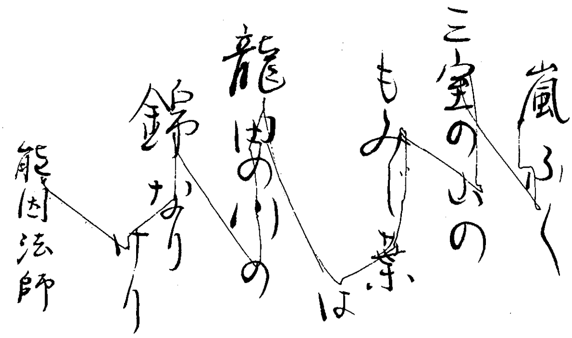

Figure 2. A Japanese poem and the eye movement trace on reading the poem.

the threshold for light detection during the saccade [8–10]. Consequently the input of information must be carried out during the fixation periods. We may then ask how large the functional visual field is at each fixation point. It can be neither infinitely large, nor infinitesimally small. There must be an appropriate size in between, which we can determine. The field may be called the *dynamic functional visual field*, in contrast to the static functional visual field as the eyes are moving over the stimulus.

To obtain the size of the dynamic functional visual field, a technique was used to artificially limit the visual field size by varying degrees [11–16]. The time to complete perceiving a stimulus was measured and a critical field size was obtained below which the perception time began to increase when compared to the normal perceiving time. The critical size should correspond to the dynamic functional visual field.

3. Apparatus

Figure 3 shows a schematic view of the apparatus used to provide a restricted visual field. A picture stimulus was presented on a T.V. monitor, with a T.V. camera at the bottom to be observed by a subject situated at a distance of 1 m. The stimulus, however, appeared on the monitor only partly within a rectangular form, the size of which was determined by a rectangular form on an x–y oscilloscope. A T.V. camera

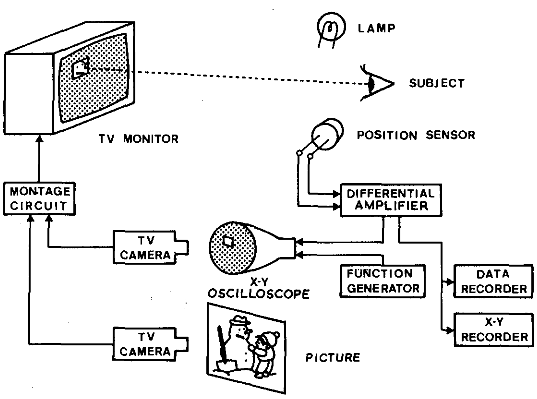

Figure 3. The apparatus for providing a restricted visual field size.