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Static and dynamic functional visual fields

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Abstract. The size of visual field utilized by the human visual system to input information about the outside world was investigated for static and dynamic viewing conditions. In static conditions, subjects detected a target that was presented in a peripheral position while maintaining central fixation. The size depended greatly on the imposed task: a large field to detect a spot of light, a small field to distinguish a target from background noise, and a still smaller field to distinguish a target from background noise while detecting a figure in the central visual field. In the dynamic condition, subjects read sentences or perceived pictures with restricted sizes of visual field and a critical field size was determined which assured normal perceptual behaviour. The size was about 10° visual angle in both cases, which was quite large compared to the saccadic size of the eye movement, implying a need to input the entire pattern for a limited time. Reasons for such short inputting times are discussed.

1. Static functional visual field

The visual field is defined as that portion of space in which objects are simultaneously visible to the steadily fixating eye [1]. In most clinical applications, the objects are simple light spots and it is well known that the visual field for such light detection may become very large by making the best use of a round eye. The visual system, however, has to engage in many different types of work rather than just a mere detection of light spots. It is important, therefore, to investigate the visual fields for various other tasks and to classify the visual fields according to the tasks imposed upon the subjects. For example, the visual field for reading letters or recognizing figures may be studied. This can be done by asking subjects to detect letters or figures that are presented at various locations in the peripheral retina while requiring subjects to fixate carefully. The visual field for letter detection is obviously much smaller than the visual field for detecting light spots. The field for detecting mere light spots may be called the *sensation visual field* and the field for reading letters or recognizing figures may be called the *visibility visual field*.

From the engineering point of view, the latter visual field is more significant than the former as everyday tasks involve detecting figures and letters rather than mere light spots. However, both visual fields may still suffer from a limited applicability, if we are to mention the engineering use, because situations simulated in the experiment, namely where targets appear in a clear open space in peripheral locations, are rather rare in real situations.

Suppose, for example, we are walking outdoors or driving a car. We accumulate information from signs, signals, figures, people, and so on, through our visual

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in front of the oscilloscope fed the rectangular form to the T.V. monitor via a montage circuit to mask the picture so that the rest of the area beside the rectangular form on the T.V. monitor was uniformly white.

The eye position of the subject was detected by the corneal reflection method, utilizing a position sensor placed close to the right eye. The x and y coordinates of the eye position were fed into the x–y oscilloscope to control the position of the rectangular form on it. Once the adjustment was made so that the visual axis coincided with the centre of the rectangular form on the T.V. monitor, the subject could observe only the stimulus within the rectangular form wherever his eye moved over the stimulus, yielding an effectively restricted visual field.

The subject's left eye was covered by a bandage and he held his head still against a biting board.

4. Results

4.1. *Visual field for reading sentences*

The size of the functional visual field for reading Japanese sentences was first investigated by putting a sentence stimulus in place of the picture in figure 3. The stimulus was composed of three rows of sentences arranged horizontally, one row containing 18 letters and subtending a visual angle of 13·8°. Six visual angles of field size were investigated: 2°, 3°, 5°, 8°, 13° and 20°. Thirty stimuli were prepared for each visual field size.

Three examples of eye movements are shown in figure 4, for field sizes, 20°(a), 8°(b) and 2°(c). Only a horizontal eye movement was used. The vertical axis in the figure gives time duration, a section corresponding to 0·5 s. The relative size of the narrowed visual field is indicated on the right for comparison with the stimulus size. With a large visual field of width of 20°, the saccades were large and the time taken to read the stimulus, namely $T_2 - T_1$, was small, while with smaller visual fields ($s = 8°$ and 2°) the saccades became smaller, the fixation time became longer, and consequently the time needed to read the stimulus became longer.

The reciprocal of the time duration, $1/(T_2 - T_1)$, defines the reading speed, and it was obtained for all visual field sizes and all five subjects. The mean value of the reading speed is plotted against the visual field size in figure 5. At the bottom is shown the visual field size in number of letters and at the top in the visual angle in degrees. A fast reading speed of about 12 letters per second was achieved with large visual fields of 20° and 13°, but it began to decrease at a certain visual field size, s_c, which is about 10°, corresponding to 13 letters. This critical size is the one that we wanted to obtain, namely the size of dynamic functional visual field for reading. It is interesting to note that the curve, when extrapolated, intersects with the abscissa at about 0·9 letters, which gives the minimum field size for reading.

It is noted from figure 4 (a) that the saccadic sizes are about 4° with the visual field of 20°, or practically a non-restricted field. The analysis of all saccadic sizes for this visual field size gave a mean value of 3·6°—much smaller than the s_c value. The implication is that normal reading requires much redundancy in covering sentences with the visual field.

The above findings indicate that for normal fast reading the visual system must be equipped with a large dynamic visual field. If such a large field is not provided, the visual system will have trouble in reading sentences, as is demonstrated by a sharp

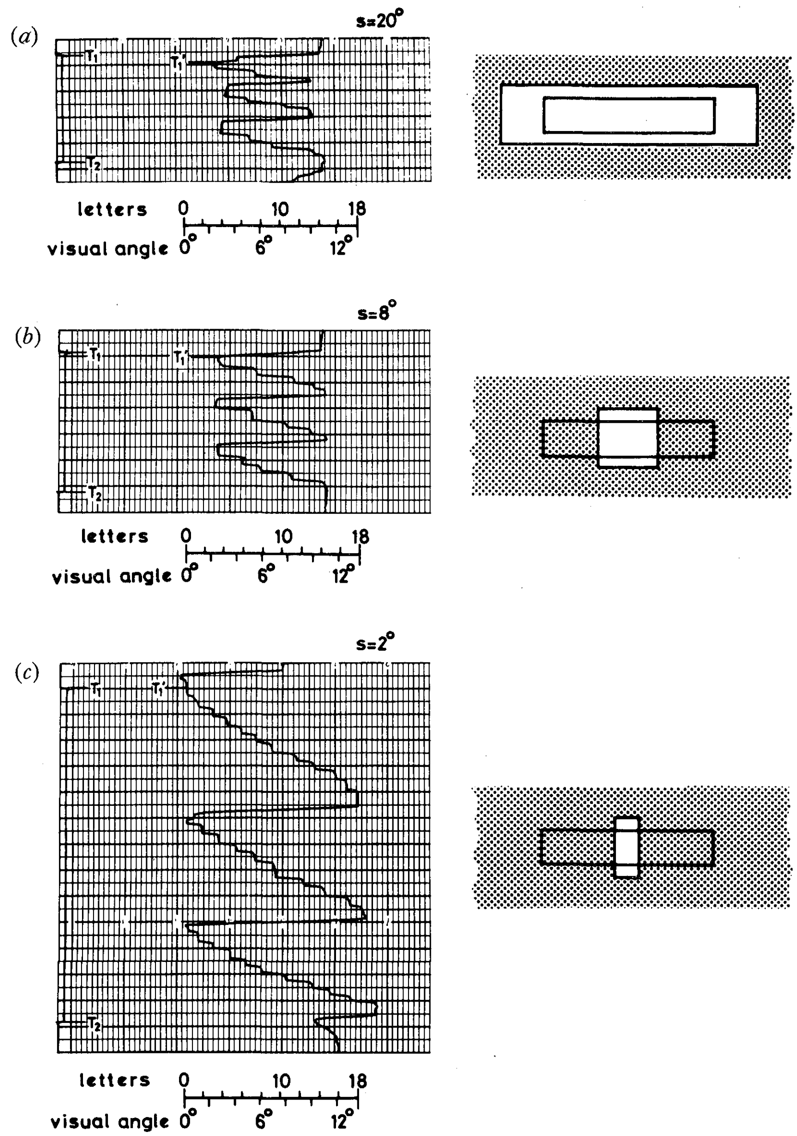

Figure 4. Eye movement traces for reading Japanese sentences with three different visual field sizes: (*a*) $s = 20°$, (*b*) $s = 8°$ and (*c*) $s = 2°$. To the right is shown the size of the visual fields relative to the sentence stimulus. The shorter rectangles indicate the stimulus size and the taller, white rectangles the visual field sizes employed.

drop of reading speed at smaller visual fields in figure 5. The suggestion can be made about the learning process of infants or foreigners in reading languages, that their low reading speed might be due to a narrowness of their functional visual field.

Figure 6 shows the eye movements of a 26-year-old American who lived in our country for two years to learn Japanese after earning her master's degree from a U.S. university. One division along the horizontal direction corresponds to 0·4° of visual angle, and that along the ordinate to 0·5 s. In (*a*) she read English shown at the top

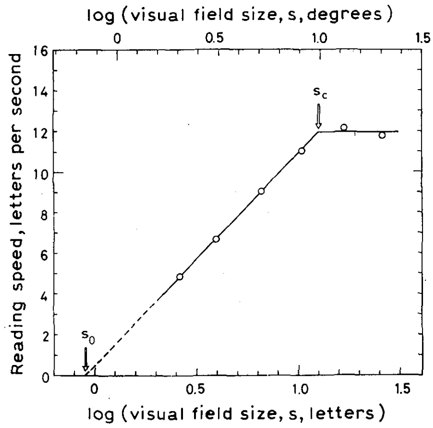

Figure 5. Reading speed as a function of visual field size. The visual field size is taken along the abscissa in the number of letters (bottom) and in the visual angle (top), both in logarithmic units.

without any field restriction, in (*b*) she read a very simple Japanese sentence composed only of 'hiragana' without any visual restriction, and in (*c*) she read English with a visual field restricted to 1°, as indicated by the square on the sentence at the top. The extreme similarity of eye movements between (*b*) and (*c*) suggests the narrowness of her visual field for Japanese sentences.

4.2. *Visual field for perceiving pictures*

The size of visual field for perceiving pictures can be investigated in the same way as for reading by feeding pictures to the T.V. monitor through the bottom T.V. camera of figure 3. An unmasked square on the T.V. monitor moved two-dimensionally and synchronously with the subjects' eye movements to provide an artificially restricted visual field. How people experience a difficulty in perceiving pictures when their visual field is narrowed down can be demonstrated qualitatively by their eye movements. The picture at the top in figure 7 (*a*) shows a woodcut print, *A Sudden Shower* by Hiroshige, a famous artist of the nineteenth century. Passengers and plankeen bearers are hurrying up and down the hill in a sudden evening downpour. When a subject looked at this picture for 1 min with a normal visual field, his visual axis moved back and forth mostly over the people and occasionally over other parts of the picture, as shown in figure 7 (*b*). With a restricted visual field, however, the eye moved rather randomly over the entire picture, being unable to concentrate on any particular points, as shown in the figure 7 (*c*). He was clearly experiencing difficulty in perceiving the picture. The size of the restricted field in this particular case was $3{\cdot}6^\circ \times 3{\cdot}6^\circ$, as indicated by the square, while the entire picture was $22^\circ \times 14^\circ$ in size.

We used a somewhat indirect method to derive quantitatively the speed of processing pictures as a function of visual field size. It was a method called pattern recognition memory, which was composed of two experimental phases. In the study phase, subjects observed 80 different pictures with a certain visual field size and with four different exposure durations, 20 pictures being prepared for each duration. In the test phase, when the subjects were given the above 80 pictures plus 80 new pictures, well shuffled, they observed them one by one for 2 s without any field

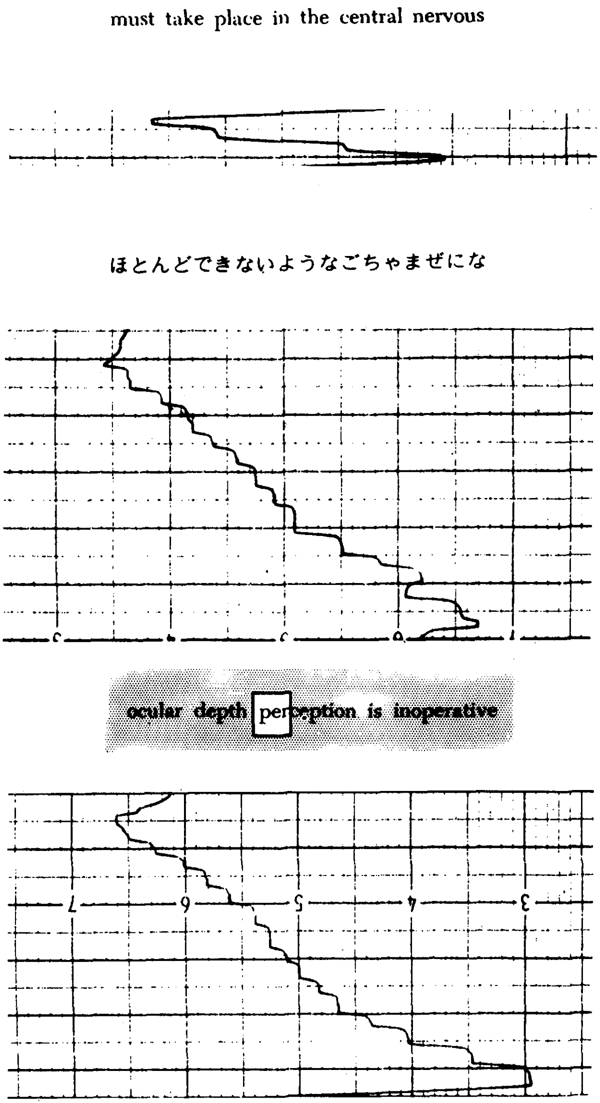

Figure 6. Eye movement traces of an American who read (*a*) an English sentence with a non-restricted visual field, (*b*) a simple Japanese sentence with a non-restricted visual field and (*c*) an English sentence with a visual field restricted to 1°.

(a)

(b)

(c)

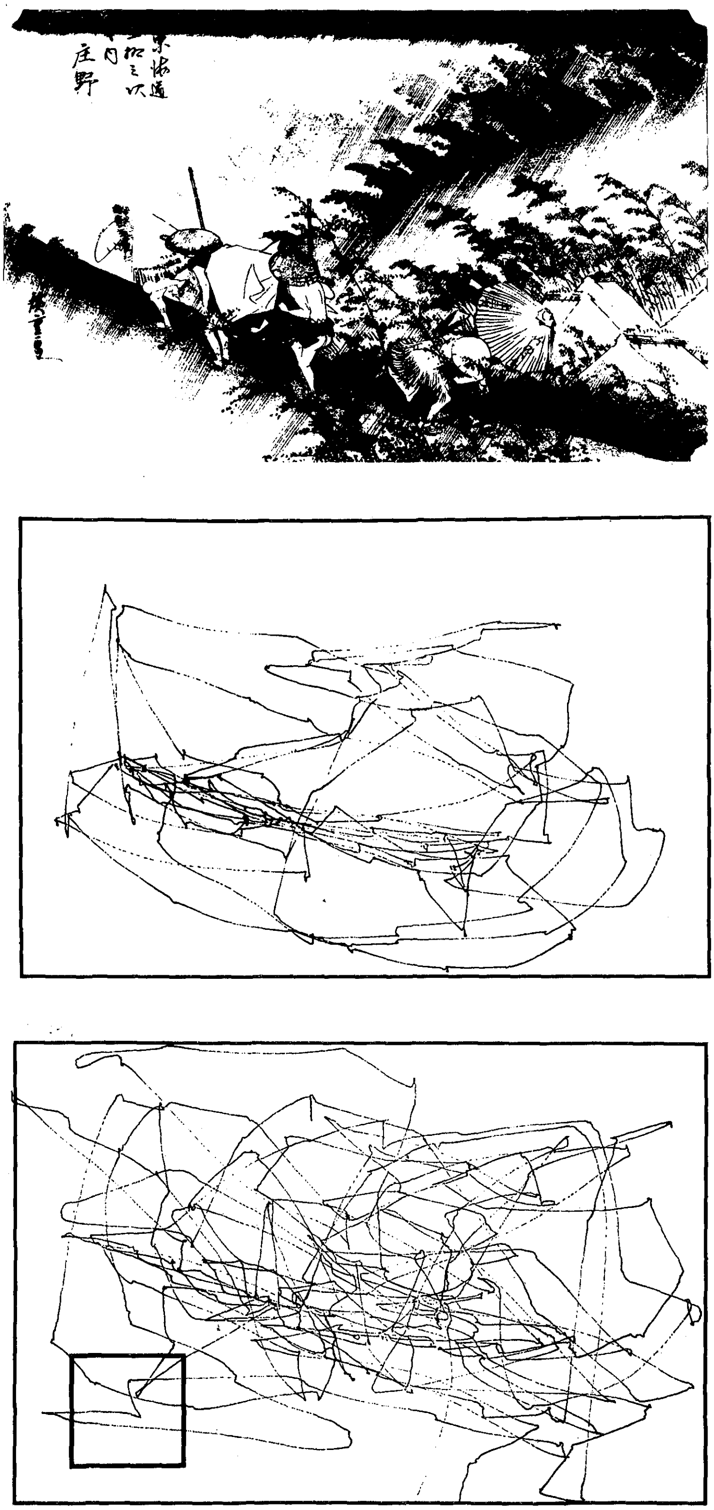

Figure 7. (*a*) A woodcut print, *A Sudden Shower* by Hiroshige. (*b*) Eye movement traces from viewing the print for 1 min without any restriction in the visual field. (*c*) Eye movement traces from viewing the print for 1 min with a visual field restricted to the size shown by the square.

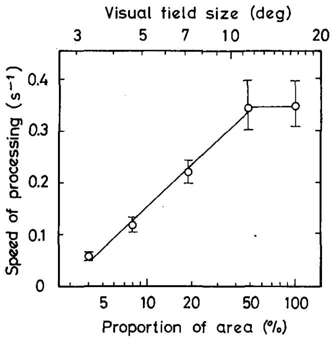

Figure 8. The speed of processing a picture as a function of visual field size.

restriction, and detected pictures shown in the study phase. A curve was obtained after two sessions of this procedure which showed the percentage of correct responses versus exposure duration. We then defined the speed of processing a picture for this particular field size as the reciprocal of the exposure duration that corresponded to the 70 per cent correct response point. A similar procedure was conducted for four other visual field sizes and the speeds were obtained for all five visual field sizes, which are plotted in figure 8. Each stimulus was $18{\cdot}8^\circ \times 14^\circ$ in size, and the visual field sizes investigated were $3{\cdot}3^\circ \times 3{\cdot}3^\circ$, $4{\cdot}5^\circ \times 4{\cdot}5^\circ$, $7{\cdot}3^\circ \times 7{\cdot}3^\circ$, $11{\cdot}4^\circ \times 11{\cdot}4^\circ$ and $21^\circ \times 16^\circ$.

The abscissa of figure 8 represents the visual field size, shown at the bottom as the percentage of the area of the entire picture that was viewed, and at the top as the side length of the square field. It is clear that pattern perception becomes harder as the visual field is reduced, and that there exists a critical visual field size to distinguish normal perception from deteriorated perception, which is the size of the dynamic functional visual field. The size is about $11^\circ \times 11^\circ$, or roughly 50 per cent of the entire picture area. We repeated the experiment as described above, except that the linear dimension of the stimulus was halved, and again obtained the functional visual field size as 50 per cent of the entire picture area. Our visual system seems to require quite a large visual field to operate normally in perceiving pictures.

5. Discussion

Why do we need a large dynamic functional visual field? The answer is not obvious. We feel, however, that the time taken to input the entire picture pattern into the visual system plays an important role in determining whether the pattern is perceived normally. With a small visual field, it takes a long time to scan the whole picture, lengthening the time to input an entire pattern into the visual system. To investigate how such lengthening may cause trouble in perceiving a pattern, we presented subjects with a picture that was optically sectioned into 5×5 portions and illuminated one portion after another in succession in a random order [17]. The total duration of the presentation was varied from 120 to 2400 ms and the subjects judged whether they perceived the picture as a united and coherent pattern, which is a necessary condition of the establishment of *the visual image*. We found that about 500 ms was the maximum time for which a visual image could be built up. With longer total times, subjects failed to perceive the stimulus as a united and coherent picture. When we have only a small visual field, the time needed to input the entire picture easily exceeds this duration and perception should become difficult.

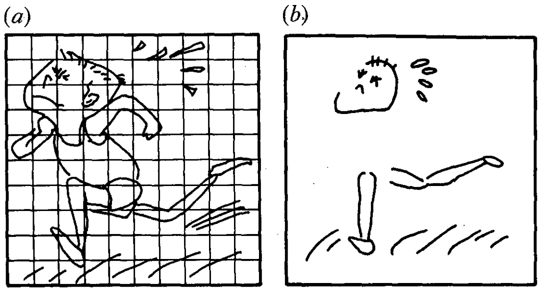

Figure 9. (*a*) A stimulus pattern sectioned into 100 portions to be presented portion by portion. (*b*) A picture drawn by a subject after he failed to perceive the pattern in (*a*).

As an example of an extreme case of prolonged inputting duration, we presented a subject with a picture, like that shown in figure 9 (*a*). sectioned into 100 portions. Here the subject illuminated the portions himself by pressing one of 100 switches at a time. He could light any portion as many times and for as long as he wished, and the order of illuminating the portions was not restricted. How did he perceive the picture? The result was that he was unable to reach any idea about the picture at all, and he gave up after 5 min of continuous observation.

An interesting thing was that he could still draw the picture afterwards, as shown in figure 9 (*b*). This is not too bad after all, and indeed the subject himself immediately recognizes it as a boy running when he saw it with his eyes. Even an incomplete picture like this was enough for him to recognize if he could utilize a normal visual field size and establish the visual image.

A wide visual field is extremely important to be able to perceive pictures [18], read sentences [16] and estimate the size of patterns [15]. People who unfortunately lack a wide visual field, such as those who suffer from tunnel vision, should experience difficulty in perceiving patterns. The case of early blindness may also be understood in the same way. Here sight is lost at an early age, but may be restored by an operation in adulthood. It was reported, however, that patients operated on successfully were almost totally unable to perceive patterns in the early stages, although their optical system had recovered perfectly [19–21]. Torii and co-workers [20, 21] measured the static sensation visual field size of one such patient using a perimeter and found that it was very small indeed just after the operation, but that it became wider as her ability to perceive patterns increased. The patient's report, when she looked at a triangle, also suggested a small dynamic functional visual field at an early stage but a larger field later on. The number of corners that she could see at any one time increased with age. Her recovery for pattern perception was closely related to the expansion of the visual field size.

We may mention yet another reason for the difficulty in pattern perception with a small visual field size. Subjects with a very small artificial visual field in our experiment often expressed a complete lack of locational relationship between two successive portions that they saw on the T.V. monitor. The reconstruction of a picture by assigning its portions to correct locations was becoming harder for them. Torii also noticed that a patient suffering from early blindness preferred to move a picture in front of her eyes with her hands to scan it rather than move her eyes over the picture.

Round human eyes are not accidental. They are easy to rotate and have a large visual field. These two features are not independent but operate in a well-balanced manner.

Die Größe des vom Menschen benutzten Gesichtsfelds wurde unter statischen und dynamischen Bedingungen untersucht. Bei statischen Bedingungen war eine peripher angeordnete Marke bei zentraler Fixation zu entdecken. Die benutzte Gesichtsfeldgröße hing stark von der zu lösenden Aufgabe ab: Ein großes Feld ergab sich, wenn bloß ein Lichtfeld zu entdecken war, ein kleines Feld, wenn ein Objekt von störender Hintergrundhelligkeit zu unterscheiden war und ein noch kleineres Feld ergab sich beim Erkennen einer Marke bei störender Hintergrundhelligkeit und gleichzeitigem Erfassen einer Figur im zentralen Sehfeld. Unter dynamischen Bedingungen lasen die Probanden Sätze oder nahmen Figuren bei eingeschränkten Sehfeld wahr; es wurde eine kritische Sehfeldgröße ermittelt, die gerade noch normales Wahrnehmungsverhalten sicherstellte. Der betreffende Sehwinkel betrug in beiden Fällen etwa 10°, was im Vergleich zur sakkadischen Augenbewegung sehr groß ist und die Notwendigkeit einer begrenzten Dauer des Einlesevorgangs impliziert. Es werden Gründe für solche kurzen Einlesezeiten diskutiert.

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