# Visual conspicuity as an external determinant of eye movements and selective attention



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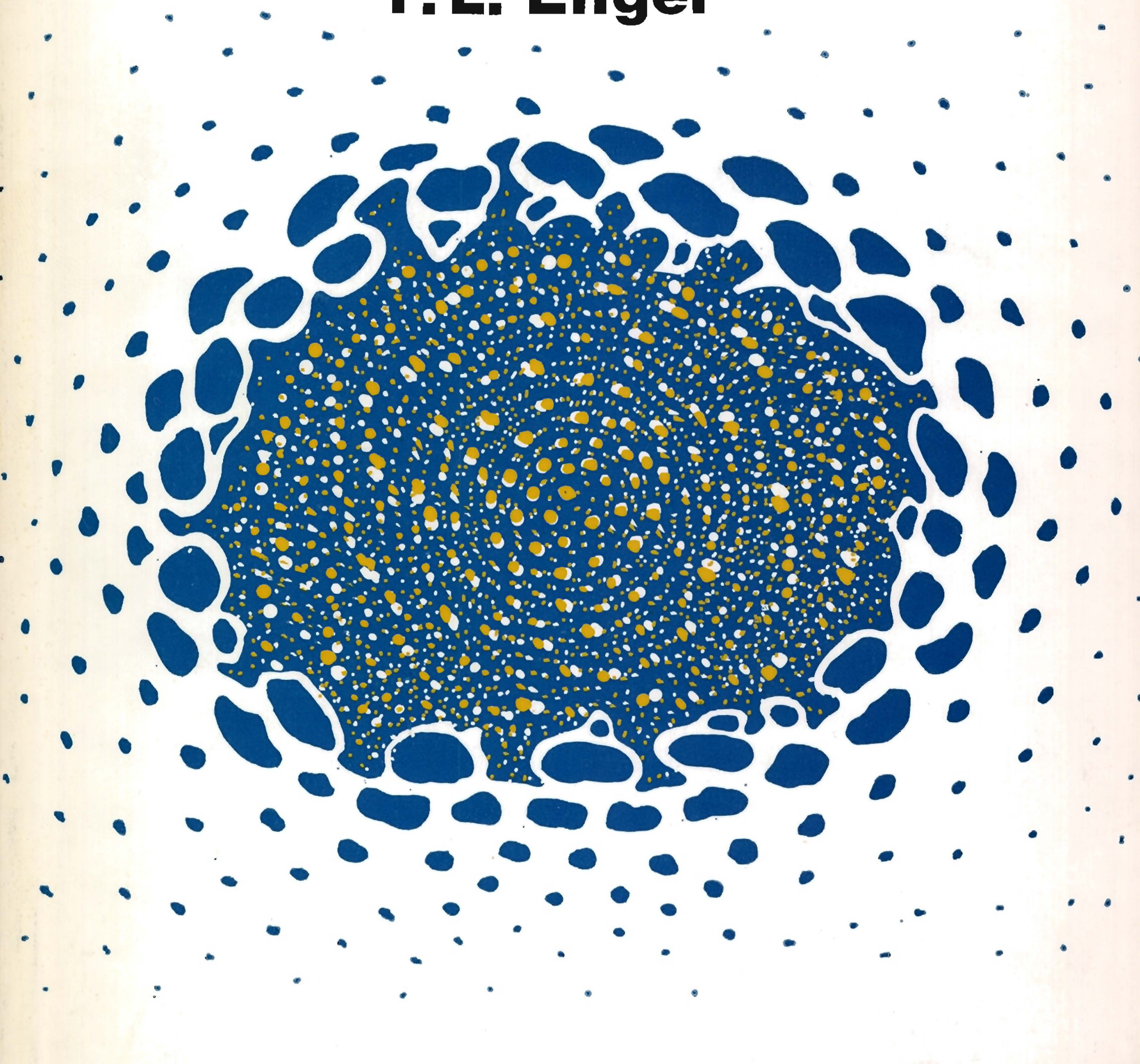

# VISUAL CONSPICUITY AS AN EXTERNAL DETERMINANT OF EYE MOVEMENTS AND SELECTIVE ATTENTION

## PROEFSCHRIFT

TER VERKRIJGING VAN DE GRAAD VAN DOCTOR IN DE TECHNISCHE WETENSCHAPPEN AAN DE TECHNISCHE HOGESCHOOL EINDHOVEN, OP GEZAG VAN DE RECTOR MAGNIFICUS, PROF. DR. P. VAN DER LEEDEN, VOOR EEN COMMISSIE AANGEWEZEN DOOR HET COLLEGE VAN DEKANEN IN HET OPENBAAR TE VERDEDIGEN OP DINSDAG 14 DECEMBER 1976 TE 16.00 UUR

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PROF. DR. J. F. SCHOUTEN EN PROF. DR. W. J. M. LEVELT

*Aan mijn ouders*
*Aan Ineke en Henk-Jan*

**Cover design:** A. van der Wenden.

If a random dot pattern is superimposed on a second identical pattern and rotated slightly, a circular moiré pattern is immediately perceived. If the contrast of the second pattern is reversed, the circular pattern is no longer observable. On the cover of this thesis similar effects are demonstrated with coloured patterns *).

The dot patterns on the front and back cover are identical, except that the colours yellow and blue have been interchanged. The spatial correlations present between the white and yellow dots (front cover) are easily observed, while the same spatial correlations between the white and blue dots (back cover) are hardly perceptible. In section 5.4 this ability, to perceive configurational aspects of visual patterns by means of similarity grouping, is discussed in relation to visual conspicuity.

*) For further details see: L. Glass and E. Switkes, Pattern recognition in humans: correlations which cannot be perceived, Perception **5**, 67-72, 1976.

**Acknowledgement**
The work described in the chapters 2 and 3 has already been published in Vision Research, Pergamon Press, Oxford, G.B., while that described in chapter 4 will appear in due course in the same journal. Permission to reprint these publications as part of the present thesis is hereby acknowledged.

## CONTENTS

# 1. GENERAL INTRODUCTION

This experimental investigation deals with the intriguing processes of information selection in the human visual system, i.e. information selection as it results from the movements of our eyes and the focussing of our attention. Their external control, by what is defined as "visual conspicuity", constitutes the main point in this study.

Visual conspicuity is understood to be the degree of perceptual prominence of a visible object in its surroundings by virtue of crude sensory features, such as differences in brightness, colour, outline, size, movement etc. This concept thus refers to sensory aspects of the stimulus in relation to its background.

An object may also be conspicuous by virtue of more cognitive aspects e.g. its novelty or its meaning. A newspaper headline, for instance, will be visually conspicuous through its relatively enlarged size of type, and moreover, it may be cognitively prominent through its importance. Since "cognitive conspicuity" is regarded as more specific to the individual observer, i.e. dependent on specific interests of the observer and on his personal experiences, and since we have aimed at studying (innate) selection-controlling factors that are common to everyone, the experimental investigations have been focussed on what in general may be called "sensory conspicuity", and in our case more precisely visual conspicuity. Greater systematic knowledge of visual selection is of both scientific and practical interest. Practical problems related to this field of research are encountered for instance in the design of traffic signals and in the evaluation of visual product inspection in industry.

In the following parts of this introductory chapter we shall first consider the selective processes involved after which the factors that control these processes will be briefly discussed. An account will then be given of the experiments performed, and their layout in this thesis will be indicated. Finally a glossary of terms is supplied as a guide to the terminology used.

## 1.1. Selective processes

The selectivity of vision, and more generally that of perception, has long been recognized. Its recorded history can be traced back to Aristotle (see Glanville and Dallenbach [1-1]), who asserted for instance that the mind is limited to the consideration of a single object. It is evident that a drastic reduction of information is indeed involved in the perception of our complex environment.

Orienting reactions, such as cupping the ears, touching objects with the hands or turning the head and eyes towards the source of interest, are obvious indications of input selection. When the eyes are directed towards the object of interest, the object becomes projected on the fovea, i.e. that small central area of the retina which possesses the highest acuity. Although peripheral vision is inferior in acuity to central vision, it nevertheless plays a significant role in establishing interrelationships in pattern perception. For instance, by electronically limiting peripheral vision, Watanabe and Yoshida [1-2]) demonstrated the observers' inability to recognize whole visual patterns from the individual foveal samples. As suggested by Hochberg [1-3]) and supported by experiments described in this thesis, information picked up in peripheral vision also plays a role in the guidance of successive eye movements.

The eye movement phenomenon is, however, not the only selective process in vision. After entering the retina, information is further reduced by what is broadly referred to in the literature as "selective attention". This somewhat loose term refers to the observer's ability to attend selectively to a certain aspect of the signals that have already entered the sense organs.

Although it is probably true that in vision the locus of attention and the line of sight are more often than not directed to the same item, they do not always coincide. It is quite possible to have the gaze directed to a particular point, and to attend at the same time to something in peripheral vision (as will be shown in chapter 2), or to attend to signals entering the brain through one of the other sense organs, for example the ears (Moray [1-4])). As will be discussed in chapter 5, selective attention can be divided into at least two functionally different stages, referred to as "sensory" and "cognitive" selection. In the first stage the stimuli are selected on the basis of their crude sensory properties, the second selects them further on higher cognitive aspects e.g. their specific meaning. However, the existence of cognitive selection has not always been recognized as such, so that selective attention usually stands for sensory selection. In the experimental work described in chapters 2, 3 and 4 we have therefore conformed to this usage. It is noteworthy that Berlyne [1-5]) proposed the terms "selective attention" and "abstraction" for these two stages.

In everyday language the term attention also refers to an aspect of intensity. Berlyne [1-5]) related the intensity of attention to vigilance and to the level of arousal, while Kahneman [1-6]) associated it with mental effort. We shall not go further into the details of this point, however, since the experimental work reported here mainly relates to the selective aspects of attention.

### 1.2. External and internal determinants

It proved useful to classify the factors that influence the selective processes mentioned, in line with Woodworth and Schlosberg [1-7]), into "external" and "internal" determinants of selection. The external determinants, also called object factors, relate to influences that can be assigned to object properties of the stimuli. Internal determinants, also known as subject factors, are of cognitive origin. They have to do with the subject's motives, desires and expectations. Fechner [1-8]) described the two categories respectively as involuntary and voluntary determinants of attention.

Visual conspicuity is defined as that sensory attribute of a visible object in its surroundings by which it is able to control sensory selection via the visual system. More operationally, visual conspicuity is taken to be the object factor determining the likelihood that a visible object will be noticed against its background by virtue of its sensory aspects, its (retinal) position not being known beforehand. The visual conspicuity of an object in its surroundings has to be distinguished from its visibility. For instance a specified object, located among identical objects, may be visible during a certain glance of the eyes, although it is inconspicuous at the same time. In our experiments the "visibility" of an object indicates the possibility to detect its presence in a given fixation position of the eyes, the observer knowing its retinal location. With foreknowledge of location the observer is then assumed to be able to attend to the relevant retinal location. Obviously visibility is prerequisite for an object to be conspicuous.

### 1.3. Experiments

The experimental work is described in the chapters 2, 3 and 4. Each chapter is one of three closely connected articles, and can therefore be read separately. Each in turn deals with two distinct topics of our research on visual conspicuity.

In chapter 2 a new measure of visual conspicuity is proposed, together with an experimental method for its determination. As a measure we propose the size of the "conspicuity area". The conspicuity area is the retinal field in which the relevant object is capable of being noticed among other objects in its background during a single eye pause without foreknowledge of its location. A more conspicuous object corresponds to a larger conspicuity area. Obviously visual conspicuity is closely related to the properties of the other objects present in the field. When foreknowledge of its retinal location is supplied, the corresponding "visibility areas" can be determined as well, which are indeed found to be larger in general than the associated conspicuity areas.

In the second part of chapter 2, the relation between visual conspicuity and visibility is considered more closely. The expectation of the observer, directing his attention (but not his eyes) towards a certain spot in the retinal field, was found to influence the shape of the retinal area concerned. The visibility and conspicuity areas turned out to be linked by directed attention.

Chapter 3 contains our results on the visibility of a test disk in eccentric vision, which was surrounded by randomly located background disks that were all identical. These background disks selectively diminished the visibility of the test disk appreciably, i.e. the ability simply to detect (not to identify) its presence with knowledge of its eccentric position. These adverse interactions of test and background disks, being in our case selective both in terms of size and luminance, are not explicable in terms of regular visual acuity data alone.

In chapter 3 we also studied how visual conspicuity is influenced by differences in size and luminance between test and background disks. In combination no mutual enhancement was observed, the stronger factor being found to govern the size of the conspicuity area.

In chapter 4 a relationship is demonstrated between the conspicuity area, yielding for a given display size the probability of target discovery in a single fixation, and the increase with time of the cumulative probability of target discovery during a search with freely moving eyes. "Target" is used here to mean the test object to be searched for. Specific "non-targets" added to the stimulus patterns, on which eye fixation had to be avoided during search for the target, were also found to be fixated at a frequency proportional to their specific conspicuity area.

As a second issue in chapter 4 a new phenomenon is described, which occurred during the determination of the conspicuity areas. For the purpose of these determinations, the observer was required to fixate strictly on the marked display centre during the brief stimulus presentations. It was found that small eye movements nevertheless occurred in the direction of the discovered target. The time delay before the occurrence of these eye movements, with respect to stimulus onset, supplied a new clue for understanding the way in which visual conspicuity influences eye movements and selective attention. Finally in chapter 4, a tentative information flow diagram is given, which includes the experimental phenomena described in this thesis.

In chapter 5 the main experimental findings are further evaluated in relation to the literature, and some new experimental results are presented. At the end a summary of this thesis is given.

### 1.4. Glossary

Although conformity with the terminology used in the literature has been aimed at, the terms and descriptions given are intended for use as a guide in this thesis only.

*Cognitive conspicuity:* the degree of cognitive prominence of a stimulus, as for example by virtue of its meaning or its novelty.

*Cognitive selection:* a selective process regarded as abstracting the meaning of the recognized item.

*Conspicuity area:* retinal field in which the relevant object can be discovered (without foreknowledge of location) in its background, during a brief presentation of the stimulus pattern.

*Discrimination area:* retinal field in which a certain difference between the test object and the background objects can be perceived, with foreknowledge of the location of the test object.

*Figure-ground detection:* ability to detect the presence of a given object in a patterned background with foreknowledge of its retinal location.

*Non-target:* a specified test object in the stimulus pattern on which eye fixation has to be avoided during the search for a specified target.

*Response set:* the subject's set enabling him to attend to stimuli that have a given specific meaning.
*Selective attention:* selective processes, responsible for the observer's ability to attend selectively to certain aspects of the signals that entered already the sense organs. Selective attention includes sensory and cognitive selection.
*Selective interference:* adverse interaction among neighbouring objects with identical features, mainly occurring in eccentric vision.
*Sensory selection:* a perceptual process regarded as selecting incoming signals by virtue of their crude sensory features.
*Similarity grouping:* perceptual grouping into larger units of neighbouring objects on the grounds of their similarity.
*Stimulus set:* the subject's set enabling him to attend to stimuli with a certain specific sensory feature.
*Target eye movement:* small involuntary movement of the eye in the direction of a target discovered.
*Visibility area:* retinal field in which the presence of the relevant object can be detected during a brief presentation with foreknowledge of its retinal location.
*Visual conspicuity:* that sensory attribute of a visible object in its surroundings by which it is able to control sensory selection, via the visual system.

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# 2. VISUAL CONSPICUITY, DIRECTED ATTENTION AND RETINAL LOCUS *)

**Abstract**

A method is proposed for measuring the visual conspicuity of an object in its background. Associated with each object is a conspicuity area, which is defined as the retinal area within which the object to be searched for is seen in a brief presentation. The size of this area can be used as a measure of visual conspicuity. Directing attention towards a certain location in the retinal field influences the shape of the retinal area concerned. Visibility and visual conspicuity turned out to be linked by directed attention. The experimental results are interpreted in terms of external and internal determiners of attention.

## 2.1. Introduction

In daily life only a very few visible objects around us are actually noticed. Some objects generally strike the attention and as a consequence are seen, while most others are overlooked unless our attention is directed towards them. Apparently our attention performs an information selection. The factors influencing this selection process can be divided into object factors and subject factors, termed external and internal determiners of attention in the phraseology of Woodworth and Schlosberg [2–1]). We consider visual conspicuity to be an object factor. More precisely, it is an object property in relation to its background, for example a red ball surrounded by similar red balls, is inconspicuous, whereas in other types of surroundings it may be conspicuous.

As we were interested in the conspicuity phenomenon, it was necessary first of all to find a measure of visual conspicuity. The first part (sec. 2.2) of this article describes the measure developed and gives an experimental method of determining visual conspicuity. The second part (secs 2.3 and 2.4) illustrate. the influence of directed attention, as an internal determiner, on the results obs tained. Finally, the relation between visibility and visual conspicuity is indicated-

## 2.2. Visual conspicuity

Conspicuous objects are easily noticed, whereas inconspicuous ones require as a rule considerable search time. We define visual conspicuity operationally as that combination of properties of a visible object in its background by which it attracts attention via the visual system, and is seen in consequence.

Various methods for measuring properties related to visual conspicuity have already been reported in the literature. Some of them, for instance the memory tests and immediate verbal reports used in advertising research, are rather difficult to interpret. More basically the influence of object–background factors like colour contrast, difference of shape, number of background objects, etc. have been investigated by measuring location time (e.g. Eriksen [2–2,3])), required

*) Vision Research **11**, 563-576, 1971.

exposure time (Boynton and Bush [2–4]) and by determining the objects fixated during search (Williams [2–5]).

In early experiments we determined the mean number of short tachistoscopic exposures required for a correct localization of a test object in several combinations of test object and background (Engel [2–6]). The subject himself controlled the moments of exposure, the exposure duration being sufficiently short to allow the subject a single eye fixation only. Foreknowledge was provided concerning the combination of test object and background. Although the rank order in the mean number of exposures required for the different combinations of test object and background was reproducible, accuracy was low. We went on by measuring the eye fixation points of the subject during the exposures. It followed from these experiments that in contrast to conspicuous objects, inconspicuous ones had to be fixated very closely in order to be reported correctly.

Consequently we circumvented the more or less random search behaviour by determining the retinal locus within which the object to be searched for was noticed in a single 75 ms exposure. We called the area concerned the "conspicuity area". As the conspicuity area expresses the chance of seeing the object during search, it is suggested that its size can be used as a measure of the visual conspicuity of the relevant object in its background.

### 2.2.1. *Stimuli*

Four pictures were used in the experiments which differed only in the test object, see fig. 2.1. The test objects were identically located in a background of straight lines of random slant and location. The test objects were drawn in such a way that no intersection with the background lines occurred.

The pictures were tachistoscopically displayed by means of a closed circuit television system. As a result of shifting and rotating the picture at will with respect to a central fixation point, the displayed test stimulus contained the test object and different parts of the same background during successive exposures. The background always completely covered the monitor screen.

The length of the background lines on the screen equalled 1.2° visual angle at 57 cm viewing distance. Line density was about 1.4 lines per square degree visual angle. The length of the sides of the test objects equalled 0.6° visual angle. The size of the black/white television monitor screen was $38 \times 29°$ visual angle. Luminances were approximately 13 cd/m$^2$ for "white" and 1.2 cd/m$^2$ for "black". We labelled the test objects in accordance with the number of constituent straight lines, see fig. 2.1.

### 2.2.2. *Apparatus*

The layout of the tachistoscopic televison system is shown in fig. 2.2.

The rest picture was a blank "white" field. Test and rest picture were made visible via the split mirror. Only one of the two pictures was illuminated at a

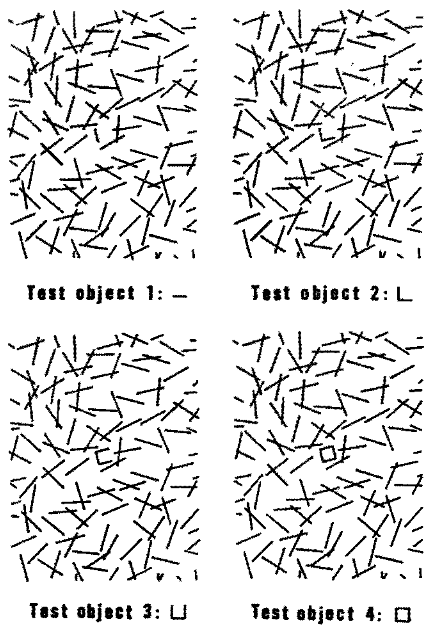


Fig. 2.1. The four pictures used in the experiments. The identical backgrounds contained one out of four different test objects on the same location. The test objects were labelled according to the number of constituent straight lines.

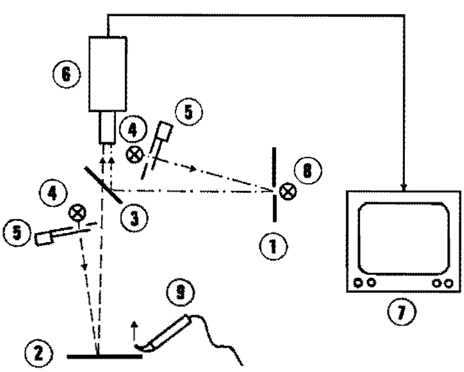

Fig. 2.2. Schematic diagram of the tachistoscopic apparatus: (1) rest picture (blank), (2) test picture, (3) split mirror, (4) lamp, (5) electro-mechanical shutter, (6) television camera, (7) one of the two television monitors, (8) fixation-light, (9) light-pen.

time by means of two electro-mechanical stepping-motor shutters. When the exposure button was depressed, the rest picture was replaced on the screen by the test stimulus for 75 ms. Test and rest stimulus were equally bright. A central fixation light remained visible during the exposure of the test stimulus. Locations in the tachistoscope field could be indicated to the subject with a glass-fiber light-pen (see experiments in secs 2.3 and 2.4). An additional monitor was available to the experimenter. Only the right eye of the subject was used, the left eye being shielded with an eye cap.

### 2.2.3. *Procedure*

The basic procedure consisted in determining in several directions up to what distance from the fixation point the test object was still completely seen by the subject in a single tachistoscopic exposure. During the measurement of visual conspicuity as an object factor, subject factors had to be as constant as possible. For that purpose stimulus exposure time was brief, minimizing the influence of eye movements and shifts of attention. The observer himself controlled the exposure button for maximum concentration. Beforehand the subject was informed about the pictures used and about the purpose of the experiment. When measuring conspicuity areas, no information concerning the test object location was provided to the subject before the exposures. This was in contrast to experiments described in the following sections. The subjects did not recognize successive stimuli as parts of one larger picture. A training session preceded each of the area determinations.

First the experimenter adjusted the test picture in the desired position in the tachistoscope. The subject had to fixate the fixation spot and when ready, to push the exposure button. Next, if the test object was seen, the supposed location and local orientation of the test object had to be reported by the subject. Afterwards the test picture was displayed again for a longer period, so that the subject too could verify the answer. Meanwhile the experimenter recorded on a transparent sheet in front of his monitor the location and orientation of the test object, together with the response of the subject. This procedure was repeated until the area within which the test object was seen was determined with sufficient precision on the experimenter's monitor screen.

### 2.2.4. *Results*

During a period of training the areas became larger, after which they remained constant for each subject. Individual differences were relatively small. The borders of the conspicuity areas determined were quite sharp, the inaccuracy was in fact slightly larger than the size of the test objects. Figure 2.3 illustrates the different conspicuity areas of the combinations of test object and background indicated in fig. 2.1, for the right eye of subject J.D.

The conspicuity area of test object 4 was the largest in our series with the

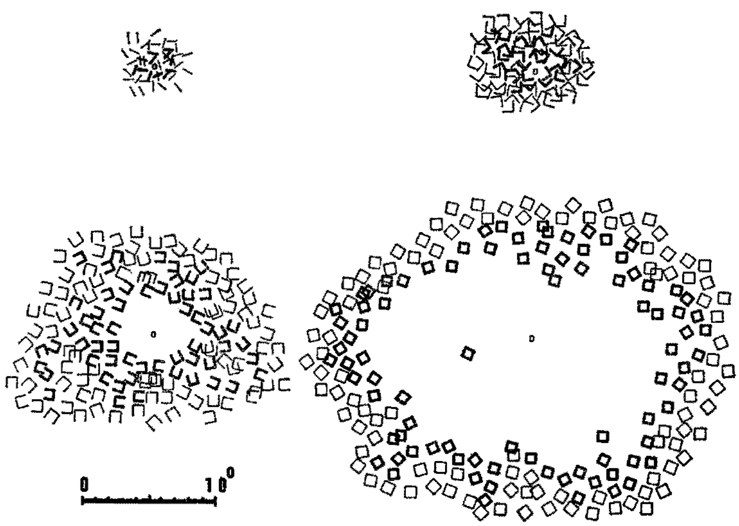


Fig. 2.3. Differences in conspicuity area of the four test objects in a background of straight lines, for the right eye of subject J.D. Test objects indicated with bold lines were reported correctly, those in thin lines were not seen or not correctly reported to be seen. Test object sides equalled 0.6° visual angle. (0) Fixation spot.

background of straight lines, whereas the area of test object 1 was the smallest. This finding agrees with the results of our early experiments, where test object 1, in contrast to 4, had to be fixated almost completely in order to be seen in this background (Engel [2–6]). The mean number of required exposures was also the largest for test object 1.

As a result of the present experiments we propose the size of the conspicuity area as a measure of visual conspicuity.

## 2.3. Detail visibility

Detail visibility indicates the extent to which the object can be seen in the experimental circumstances, while the attention is directed towards it. The conspicuity areas having been determined, the question arose whether the conspicuity loci obtained were identical with visibility limits. To investigate this, "visibility areas" were determined as well.

### 2.3.1. *Stimuli and apparatus*

Stimuli and apparatus were identical with those used in the conspicuity area experiments.

### 2.3.2. *Procedure*

The procedure too was identical, except for the fact that the subject was now pre-informed on the location of the test object by means of the light-pen. Only the local orientation of the test object was unknown to the subject. Consequently the subject would direct his attention beforehand to the indicated location, while maintaining fixation at the fixation point. On a ready sign from the subject the light-pen was quickly removed, after which the subject pushed the exposure button. When the subject saw the test object, he had to report its local orientation. Correct eye fixation was checked by means of an eye movement apparatus, based on the cornea-reflection method, as described for instance by Yarbus [2–7]). Generally speaking, the fixation deviations remained within 1° visual angle.

### 2.3.3. *Results*

Figure 2.4 illustrates the visibility areas obtained for subject J.D., for which are given in fig. 2.3 the corresponding conspicuity areas.

The irregularities in the shape of the visibility and conspicuity areas were reproducible, indicating relative scotomata. This local decrease in sensitivity may be due to retinal blood vessels (Le Grand [2–8])) or to peculiarities of the neural organization.

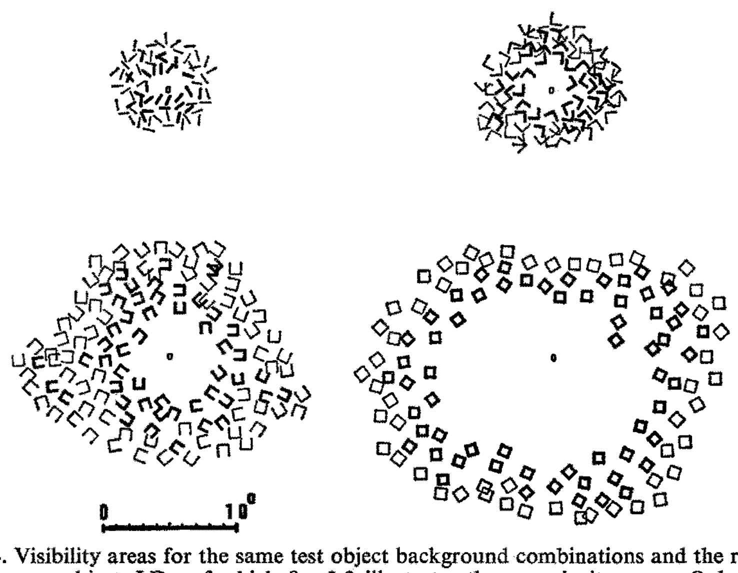


Fig. 2.4. Visibility areas for the same test object background combinations and the right eye of the same subject J.D., of which fig. 2.3 illustrates the conspicuity areas. Only the test objects indicated with bold lines were reported to be seen correctly when the subject was informed about the test object location before each exposure. Test object sides equalled 0.6° visual angle. (0) Fixation spot.

Figure 2.5 illustrates the relation between the visibility and conspicuity area size for the different stimuli in the background of straight lines.

The indicated averaged values were normalized in order to compensate for individual differences. The size of the conspicuity area of test object 4 was used

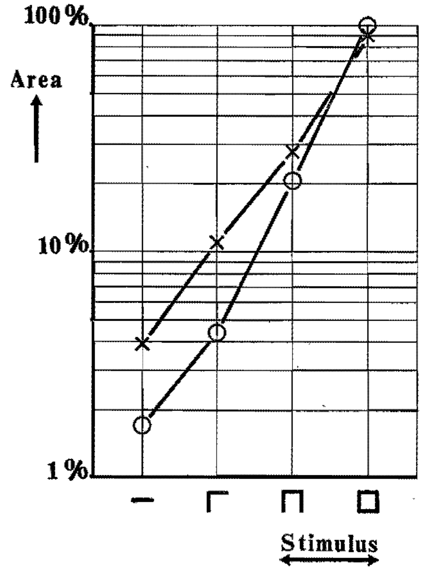


Fig. 2.5. Sizes of visibility and conspicuity areas, for two subjects averaged and normalized on the size of the conspicuity area of test object 4. (×) Visibility, (○) conspicuity.

as 100 per cent reference. The standard deviation in the area sizes was roughly 30 per cent of the corresponding mean value.

With the exception of test object 4, the visibility areas obtained were greater than the corresponding conspicuity areas, so that peripheral detail visibility was no limitation for the conspicuity areas measured. The conspicuity area for test object 4 practically equalled the visibility area, so that here the conspicuity area was limited by the visibility of the test object.

Although the subject tried to maintain the same criterion of complete detail perception, he has perhaps not quite succeeded since the visibility area of test object 4 appeared to be slightly smaller than the corresponding conspicuity area.

### 2.4. Directed attention

The conspicuity areas determined in our previous experiments supplied a measure of the object factor which we called visual conspicuity. When the subject was informed about the (retinal) location of the test object before each exposure, the object was correctly reported to be seen in a greater area, which we called visibility area. The difference in area illustrated the influence of pre-knowledge, a subject factor, on the results obtained.

We shall now investigate more closely the way in which the retinal areas, within which the test object is seen, are influenced by expectation concerning the test object location. For that purpose in addition to the central fixation point a fixed "attention point" was supplied before each exposure. There was a good chance of the test object appearing at the location of the attention point, which helped the subject in directing his attention to the attention point while fixating the fixation point. The areas obtained under these circumstances were called "attention areas" and will be shown to link conspicuity area and visibility area.

### 2.4.1. *Stimuli and apparatus*

Two different pictures were used in the experiments. These pictures contained the same background of equal, randomly located straight lines. To prevent confusion with the test object as was experienced sometimes in the conspicuity-area experiments, the background lines did not intersect each other. In the first picture test object 1 was situated. The second picture contained test object 2 on the same location. The test objects did not intersect the background lines (fig. 2.6).

The length of the background lines equalled 2.6° visual angle at 57 cm viewing distance, the sides of the test objects were 1.3°. Line density was about 0.3 lines per square degree visual angle. The pictures were displayed on a normal 38 × 29° black/white television monitor screen. Screen luminance was approximately 15 cd/m² for "white" and 1.1 cd/m² for the "black" lines. The tachistoscopic apparatus was identical with the one used in the conspicuity-area experiments.

### 2.4.2. *Procedure*

Just as for the conspicuity-area determination, the basic procedure consisted in determining in several directions up to which distance from the fixation point the test object concerned was correctly reported by the subject in a single exposure. In contrast to the conspicuity-area experiments, an additional attention point was supplied to the subject before each exposure. This point remained at

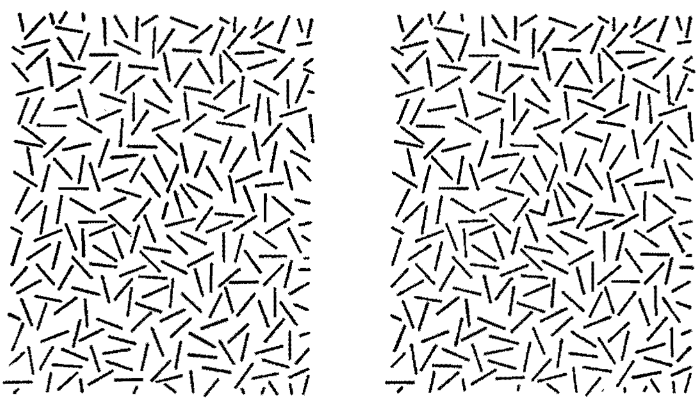

Fig. 2.6. A fragment of the pictures used. The actual backgrounds covered the complete monitor screen. Test object 1 is situated in the centre of the left picture. The right picture contains test object 2 on the same location.

the same location during the determination of one attention area. The sequence of test object locations was chosen in such a way as to maintain in the subject a high expectation level of test object appearance at the attention point.

Thus the subject had to fixate the fixation point and to direct his attention to the attention point, indicated with the light-pen. When the subject was ready, at maximum concentration of attention, the light-pen was removed, after which the subject pushed the exposure button. When the subject saw the test object, he reported its perceived location and local orientation. After each exposure the experimenter recorded the results on the transparent sheet in front of his own monitor screen. The accuracy of the eye fixations was checked as before.

### 2.4.3. *Results*

The influence of an additional attention point with a fixed location on the area obtained is shown in fig. 2.7.

In the conspicuity-area determination (sec. 2.2) no information on the test object location was provided before the exposures. The visibility area (sec. 2.3) was obtained when the test object location was indicated before each exposure.

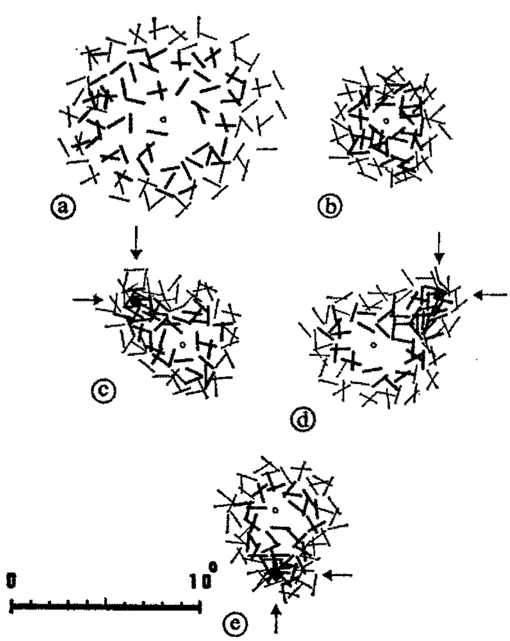


Fig. 2.7. The areas obtained for the right eye of subject S.D.: (*a*) visibility area (with preknowledge of the test object location), (*b*) conspicuity area (without preknowledge of test object location), (*c*), (*d*) and (*e*) attention areas with the attention point at three different locations. Only the test objects in bold lines were correctly reported to be seen. (0) Fixation spot, (●) attention point.

The attention areas thus obtained were practically equal to the corresponding conspicuity areas, except for an additional extension in the direction of the attention point. The determined extensions were limited by the locus of the corresponding visibility areas. The visibility area can thus be seen as being composed of the corresponding attention areas (fig. 2.8). The accuracy of the eye fixations measured during the exposures of the attention area experiments remained within 1° visual angle around the fixation point.

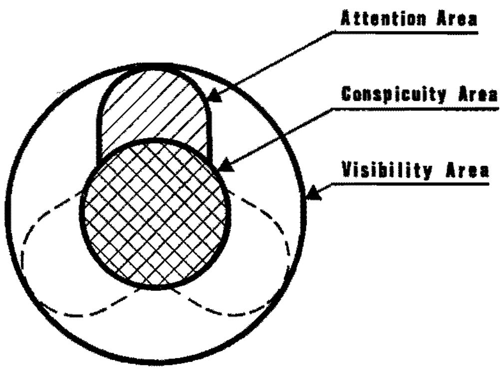


Fig. 2.8. Schematic diagram of the relation between the corresponding conspicuity, visibility and three attention areas.

At the beginning the location of the attention point was chosen near the visibility locus. Additional experiments indicated, however, that the distance between the fixation point and the attention point was not of great importance to the attention areas obtained. Only the direction with respect to the fixation point seemed to be significant in our experiment; see fig. 2.9.

## 2.5. Discussion

### 2.5.1. *Influence of conspicuity*

Although the areas we could determine were limited by the apparatus to some 20° visual angle dia. and we only illustrated the influence of form contrast as an object factor on the size of the conspicuity area, we think it likely that the conspicuity-area concept can also be applied as a measure of more conspicuous combinations, and for other visual conspicuity factors, like size, colour contrast, density of background elements, etc.

The concept of conspicuity area comes close to the "field of short time visual search" proposed by Chaikin, Corbin and Volkmann [2-9]). The conspicuity area may indeed be helpful for understanding search behaviour. The problem of search then becomes the problem of finding a strategy of directing one's eyes such that the object to be searched for falls within the conspicuity area as soon

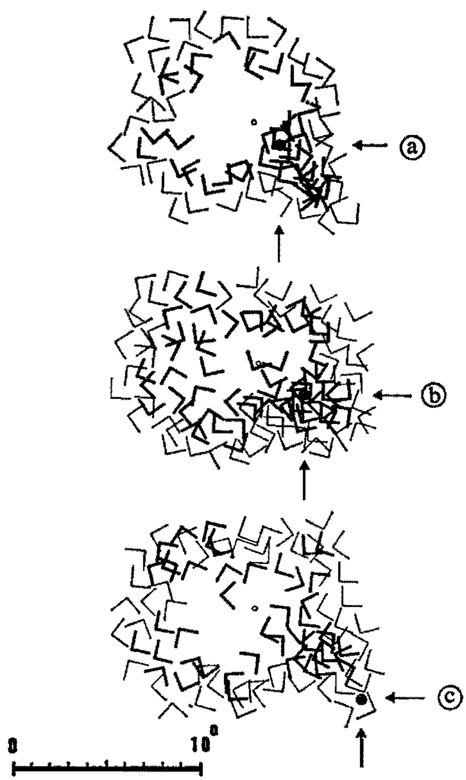


Fig. 2.9. The attention areas obtained for different locations of the attention point (●). (*a*) Inside the conspicuity area, (*b*) between the visibility and conspicuity locus, (*c*) outside the visibility area. The areas are practically equal in size and shape.

as possible. The optimum size of eye jumps should depend on the diameter of the conspicuity area. However, in pilot experiments (Engel [2-6]), the mean distance between subsequent fixation points in tachistoscopic search increased only slightly (in fig. 2.1 for test object 1 about 2°, for test object 4 roughly 3° visual angle). Statistical calculations may be used to derive search time from the size of the conspicuity area as done by Williams [2-10] in the reverse direction.

In the conspicuity area experiments mentioned the eye fixation point remained in the centre of the screen. By rearranging these results, so-called "complemental conspicuity areas" may be obtained. In these complemental areas the test object remains at a fixed position in the centre while the fixation points are indicated around the object.

Because of the allowed picture rotations the original conspicuity areas principally demonstrate retinal peculiarities (e.g. blindspot), while the complemental area notation of the same measurements will emphasize peculiarities of the background (e.g. masking by background objects).

For a first hand acquaintance with the complemental visibility area, the test object location is here known beforehand; see fig. 2.10.

Fixation within the indicated areas will lead to perception of the complete test object. Outside the complemental visibility area, the test object concerned will be seen incompletely or not at all. To a certain extent these complemental areas turn out to be independent of viewing distance, and they constitute a property of the picture configuration. This finding is in line with our preliminary measurements of the influence of picture magnification on the size of the retinal areas.

### 2.5.2. *Influence of directed attention*

Our attention area experiments indicate that a difference may exist between the spot where our eyes are fixated on, the fixation point, and the location where our attention is directed to, the attention point. The experimental results of Kaufman and Richards [2-11]) also emphasize this distinction. They compared

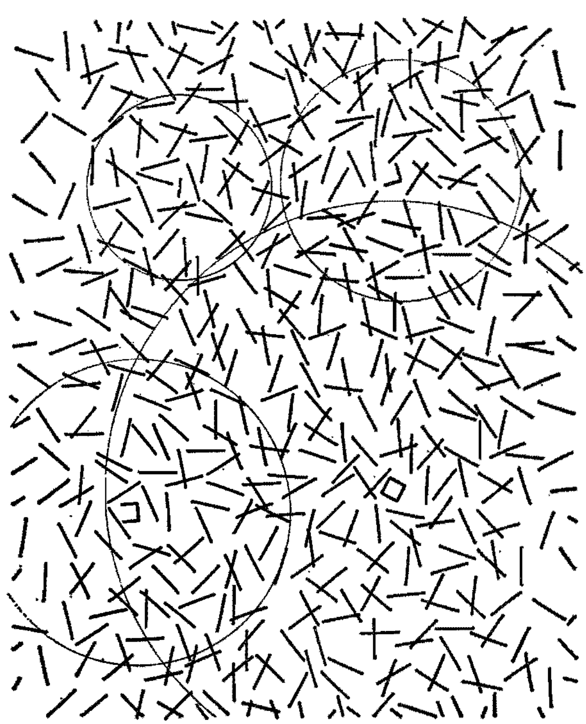

Fig. 2.10. Demonstration of the binocular complemental visibility areas. The borders in thin lines are obtained by slowly advancing one's binocular fixation point towards the test object concerned, with the aid of a pencil point. Only inside the areas can the test object be seen completely. The indicated borders are averaged results. Small deviations will be experienced depending on the criterion, individual qualities and only slightly on viewing distance (here approximately 15 cm).

the points where a naive observer believes his eyes are directed on and where the eyes are in fact oriented to. These points did not coincide.

In view of the difference obtained between the conspicuity area and the attention area, directed attention selectively emphasizes peripheral vision in a certain retinal area. Helmholtz, while looking at "complicated" stereoscopic pictures, illuminated instantaneously by electric sparks, remarked:

*It is a curious fact that the observer may be gazing steadily at the fixation mark, and yet at the same time he can concentrate his attention on any part of the dark field he likes, so that when the spark comes he will get an impression about objects in that particular region only. In this experiment the attention is entirely independent of the position and accommodation of the eyes or, indeed, of any known variations in or on the organ of vision. Thus it is possible, simply by a conscious and voluntary effort, to focus the attention on some definite spot in an absolutely dark and featureless field. In the development of a theory of the attention, this is one of the most striking experiments that can be made. (Helmholtz [2-12]), translation 1925).*

Preknowledge concerning stimulus location decreased the peripheral intensity threshold (Lie [2-13])), while the number of correct judgments for very brief exposures near time threshold increased (Grindley and Townsend [2-14]), Keeley [2-15])). Our experiments demonstrated the influence of directed attention on retinal locus. Mertens [2-16]) indicated that in the case of an isolated object, foreknowledge of position had no influence of significance upon the probability of observation. Our experiments also showed that only the conspicuous test object 4 in the background of straight lines supplied no area difference as a result of foreknowledge of position. Doubtlessly an isolated object is very conspicuous, so that probably in that case conspicuity and visibility area will be equal. This is also in line with the results of Grindley and Townsend [2-14,17]) who concluded that in peripheral vision attention acts selectively only when there is a complex pattern of stimulation.

It is interesting that only the direction of attention with respect to the fixation point and not the distance from the fixation point seemed to be significant in our experiments.

### 2.5.3. *Interpretation of results*

The results obtained may be interpreted by the tentative flow diagram of fig. 2.11.

The attention mechanism reduces the incoming information. To some extent it acts like a selective filter, which can be tuned (Broadbent [2-18])). Apart from the additional extension, the attention area equalled the corresponding conspicuity area, so that visual conspicuity and expectation concerning test object

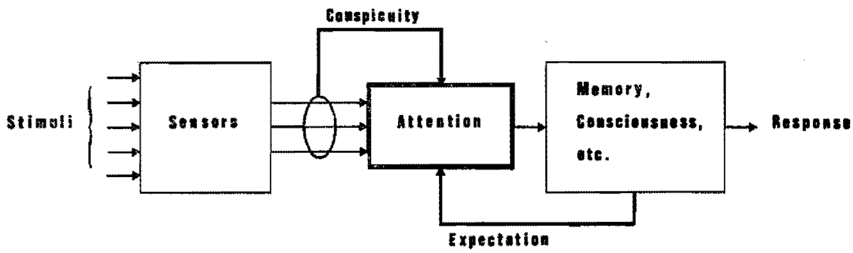


Fig. 2.11. A tentative flow diagram of the human information processing system. A major information reduction is effectuated by the attention process. The attention can be influenced both by expectation as an internal determiner of attention and by conspicuity as an external determiner.

location must be considered to be independent determiners of attention. We suppose visual conspicuity to be an external determiner of attention, while expectation concerning the test object location is understood to be an internal determiner of attention according to Woodworth and Schlosberg [2-1]). A century ago Fechner [2-19]) described them as voluntary and involuntary determiners of attention.

We suppose visibility to be determined at the sensor level. Already at the sensor level information reduction is effectuated. Masking or mutual interference of adjacent objects in indirect vision was a strong factor in our visibility experiments; much larger visibility areas will be obtained when the four test objects are in a blank white background. For a recent publication on the interaction effects see Bouma [2-20]).

As the extension of the attention area was limited by the visibility area, information reduction by visibility and by attention seems essentially a serial process. There is still considerable disagreement about the level at which selection by the attention mechanism takes place (Norman [2-21])). It is probable that information is successively reduced at the different levels of the sensory process. Here we postulate the visual conspicuity of an object in its visual background to be related to a relatively low level of processing. Other selection factors like novelty obviously has to do with memory and mental background of the subject and must be located at higher processing levels. Its influence was probably avoided in our experiments by using simple emotionless stimuli and by allowing a training period before each area determination.

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# 3. VISUAL CONSPICUITY AND SELECTIVE BACKGROUND INTERFERENCE IN ECCENTRIC VISION *)

**Abstract**
Explorative experiments are described concerning the influence of test-object background factors on the size of the so-called conspicuity area, the retinal field in which the relevant object can be discovered from its background during a brief presentation. The stimulus was a test disk, with adjustable luminance and diameter, among randomly located background disks. There was size- and luminance-selective interference by background disks on the perceptibility of the test disk in eccentric vision. The size of the conspicuity area could be described by a logical summation of the separate influences of diameter and luminance contrast relative to the background disks.

## 3.1. Introduction

Conspicuous objects are easily noticed, whereas inconspicuous ones require in general considerable search time. We define visual conspicuity to be the object factor influencing selective attention.

In a previous paper (Engel [3-1]) we proposed a measure for the visual conspicuity of an object in its background. With each object we associated a visual field, within which it was capable of being discovered in its background during a single, brief (75 ms) presentation. The size of this so-called conspicuity area, around the momentary fixation spot, was shown to indicate the ease in finding the relevant object and, accordingly reflected its conspicuity. In the background of randomly located straight lines used at that time, the four test objects, somewhat arbitrarily composed of smaller line segments, differed greatly in conspicuity area.

The conspicuity area was distinguished from the so-called visibility area, defined in the same way except that the observer was informed about the location of the object in advance. In the complex backgrounds used, the visibility areas were in general larger than the corresponding conspicuity areas, indicating an influence of the locus of directed attention.

Since for homogeneous backgrounds, both conspicuity and visibility areas were much larger, the interfering influence of the surrounding background objects was the primary cause of the reduction of these visual fields. Although literature on forward and backward masking (successive interference) is extensive (for a review see Kahneman [3-2]), simultaneous interference has been described only sporadically. Flom, Weimouth and Kahneman [3-3]) reported that at the fovea the gap detection of a Landolt-ring is affected by placing bars at some distance tangential to the Landolt-ring, the effect being supra retinal (Flom, Heath and Takahashi [3-4])). At the para-fovea letter recognition can be reduced by introducing adjacent letters (e.g. Woodworth and Schlosberg [3-5]),

*) Vision Research **14**, 459-471, 1974.

Mackworth [3-6]). The distance of letter interaction is much larger than can be expected on the basis of visual acuity data alone; according to Bouma [3-7]) it is roughly $0.5\varphi°$ visual angle for a test letter at $\varphi°$ eccentricity.

In general it is not clear on which factors these interferences are based. At the end of this paper we offer some considerations of the possibility of lateral inhibition between similar information channels as the major cause of interaction, we may expect the interference then to be as specific as the interacting channels.

In order to explore these effects more closely, we used luminous disks this time for both the test object and the background objects, thus reducing the number of parameters and lining up with literature on homogeneous backgrounds (e.g. Dubois-Poulsen [3-8])). As variables we chose the diameter and the luminance of the test disk. The background disks all of which are identical, and their configuration remained unchanged.

With these stimuli a further refinement of the threshold criterion was found to be necessary. Whenever the presence of the test line could be detected in our previous visibility experiments, its local orientation was also perceptible. When the *presence* of the test disk was detected in our present experiments, a *difference* between the test object and the background disks could not always be perceived. We therefore distinguish here between a "visibility area", in which with advance indication of location the observer can detect the presence of the test object, and a "discrimination area" where again with advance information on location the observer can perceive the difference between the test object and the background objects.

This paper will first deal with the separate influence of the diameter (sec. 3.3) and the luminance (sec. 3.4) of the test-disk on the sizes of the conspicuity, visibility and discrimination area. Next the combined influence of both test disk variables on the size of the conspicuity area will be dealt with (sec. 3.5).

## 3.2. Experimental

### 3.2.1. *Stimuli and apparatus*

The background consisted of randomly located white disks, all of them identical, on a black surface. Overlapping was prevented by maintaining a minimum centre to centre distance of 1.5 times the diameter of the background disks.

On a fixed location in this background a white test disk was placed. Of this combination of test object and background a number of slides was made on Kodalith (high-contrast) material. These slides differed from each other only in the diameter of the test disk applied. The luminance of the test disk was diminished by sticking a small piece of grey filter foil to it on the slide. Figure 3.1 shows one of these slides.

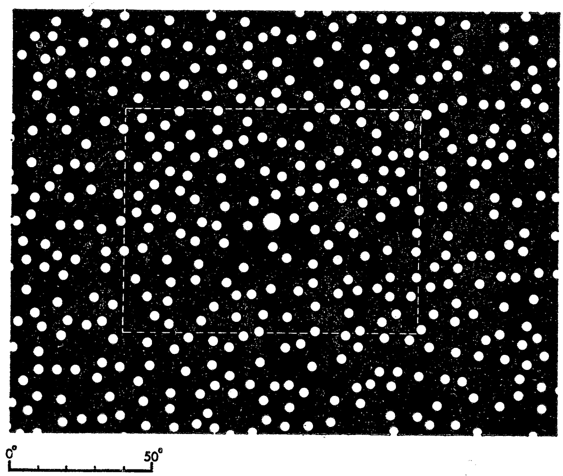



Fig. 3.1. One of the slides used in the experiments. Here the test disk is larger than the surrounding background disks, measuring 3.5° visual angle in diameter. The dotted lines indicate which part could be projected as stimulus field (measuring 100 × 80° visual angle). By shifting the slide the test disk could be displayed on any desired location of the stimulus field.

The test disk and part of the background were projected as "stimulus field" (measuring 100 cm horizontally and 80 cm vertically) for single, 80 ms periods on a translucent screen in front of the observer. This exposure time was short enough to prevent influence of possible eye movement reactions, but longer than stimulus integration time. By shifting the slide the test disk could be displayed on any desired location in the stimulus field, while the background completely filled up the rest of this field. On the average, the stimulus field contained some 130 background disks. To the experimenter the stimulus field was continuously visible on a small inspection screen, see fig. 3.2. On this screen the experimenter could, before each exposure, position the test disk at will in the stimulus field, and afterwards record the responses of the observer.

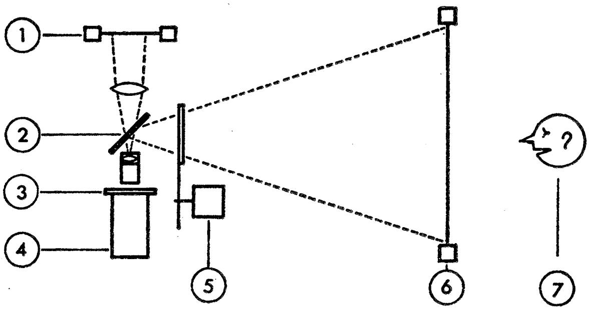



Fig. 3.2. Outline of the stimulus channel of the tachistoscopic projection system: 1 = small inspection screen; 2 = semi-reflecting mirror; 3 = movable slide; 4 = stimulus projector; 5 = torque-magnet shutter; 6 = translucent screen; 7 = observer.

The luminance of the black part of the background, as measured in the centre of the screen, was 0.65 cd/m$^2$ and 33 cd/m$^2$ for the white background disks. Owing to vignetting of the projector and to direction selective radiation of the screen, luminances in the direction of the observer gradually decreased to about one quarter of the central values at the edges. Unfortunate as it was, this had no appreciable influence on the measurements, since they turned out to depend on relative luminances mainly. For adaptation purposes a homogeneous "rest field", with a luminance equal to the averaged luminance of the stimulus field (4.5 cd/m$^2$ in the centre) was projected on the screen when no stimulus field was presented. Both fields were changed over within 8 ms by means of a single torque-magnet shutter (Mélotte and Valbracht [3-9]). A small luminous fixation spot was continuously provided in the centre of the screen.

A head rest was mounted in such a way that the right eye of the observer was in front of the fixation spot at a viewing distance of 57 cm, the left eye being shielded with an eye cap. No artificial pupil was used. The diameter of each of the displayed background disks was 3.5 cm, corresponding to 3.5° visual angle in the centre. The background disks were chosen relatively bright and large to make sure that, on a homogeneous background, they could be perceived up to the absolute limits of the visual field. The observer himself controlled the stimulus field exposure button. As a check on correctly perceived location, the observed test disk location could be indicated on the screen with an electric torch.

For visual field determinations on a plain background, use was made of a translucent semi-sphere 90 cm in diameter. The sphere had a luminance of 0.65 cd/m$^2$, corresponding to that of the dark part of the complex background. The test disk could be projected, also for 80 ms periods, from the outside at any location on this spherical screen. The sphere was provided on the inside with a head rest.

### 3.2.2. *Procedures*

In order to speed up various area determinations, borders were determined in only eight directions with respect to the central fixation spot (viz. "horizontal", "vertical" and "diagonal"). Averaged border eccentricity $\bar{R}$ was called the "size" of the visual field concerned.

*Conspicuity areas*, characterized by the property that the observer was not informed beforehand about the test disk location, were determined as follows: After giving the observer information about the test-disk background combination to be used, the experimenter adjusted the test disk at the desired position on one of the randomly chosen meridians by shifting the slide. Next, the observer fixated the fixation spot and when ready, pushed the exposure button, which made the stimulus field appear for 80 ms. If he discovered the test disk, he indicated the supposed location at the screen by means of the electric torch.

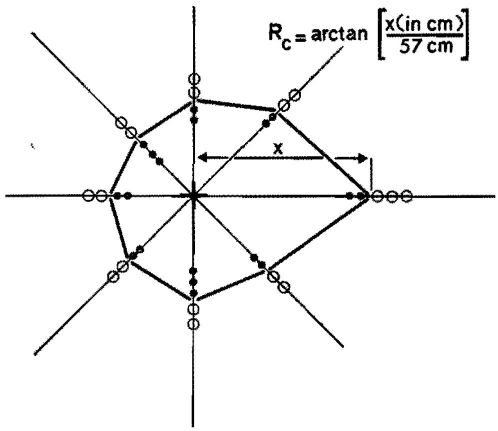



Fig. 3.3. Example of a conspicuity area, obtained by determining the threshold eccentricity $R_c$ inside which the observer could discover with his right eye the test disk in the complex background. With the size $\bar{R}_c$ of the conspicuity area we mean the average $R_c$ over the 8 directions. + = Fixation spot; ● = discovered location of the test disk; ○ = not discovered location of the test disk or an incorrect response.

Afterwards the stimulus field was presented for a longer period, so that he could verify his answer while the experimenter recorded the result on a translucent sheet attached to the control screen. This procedure was repeated until the area was determined with the required precision. For determination of a border point about 5 exposures were needed, which were intermingled with exposures at other meridians. Figure 3.3 gives an impression of a conspicuity area thus obtained.

A practice session of about 15 exposures directly preceded each area determination, during which the observer also adapted to the luminances maintained. Due to the random configuration of background disks and the arbitrary shifts of the slide before each exposure, the observer was not aided by the fact that the same slide was used for succeeding stimulus field exposures.

*Visibility areas* were characterized by the property that the observer, with foreknowledge of test disk location, could detect the presence of the test object at the location concerned. It did not imply that he also discerned a difference in luminance or diameter relative to the background disks. Starting at the fixation spot, the visibility areas were determined by shifting the test disk before each exposure with small steps outwards and inwards along the relevant meridian, meanwhile the observer reported if he detected an object at the location concerned. As a check, presentations also occurred where the test disk location deviated largely from the expected location.

As the reproducibility of the borders obtained was actually the only check of reliability in these experiments, the relevant results have been verified by determining the fraction of correct (detection) responses $P$ along the horizontal meridian of the temporal retina. These verification experiments were divided

into subsets of 20 exposures, in which the slide was not moved and the test disk appeared at random at a fixed location. Removal of the test object was accomplished by shifting a small masking dot on an additional glass plate over the slide. Also, the exposure cycle deviated somewhat from the previous experiments. When ready and fixating the fixation spot, the observer started this cycle by pushing a button, a small indication light then appeared for 80 ms at the relevant test disk location, followed 1 s later by the 80 ms stimulus field exposure. Next the observer reported (forced choice) if he had perceived the presence of the test disk, after which the experimenter replied whether the answer was correct. Some trial exposures preceded each subset.
*Discrimination areas* were characterized by pre-information concerning test disk location and by the ability of the observer to discern the introduced difference between the test disk and the background disks inside this field. These areas were determined with a procedure similar to that of the visibility areas. The correctness of eye fixation was not checked in the results to be presented since previous experiments (Engel [3-1])) indicated that experienced observers maintained their fixation sufficiently well under similar circumstances. However, afterwards, in a repetition of the verification experiments with two naive observers, we in fact checked the correctness of eye fixation by means of infrared TV recordings and got visibility results comparable to those presented in this paper. Table 3-I summarizes the characteristics of the three types of visual fields used.

TABLE 3-I

Summary of characteristics concerning the visual fields distinguished in the experiments

| visual field \ characteristics | preknowledge of location | perceptibility of presence | perceptibility of introduced difference |
|---|---|---|---|
| visibility area | + | + | – |
| discrimination area | + | + | + |
| conspicuity area | – | + | + |

### 3.2.3. *Observers*

The results to be presented were obtained from the subjects T.B. and F.E. Both were experienced observers with adequate vision, and did not need spectacles. Confirmatory results were obtained from at least two other observers.

3.2.4. *Terminology*

$D$ = diameter of the test disk,
$D_0$ = diameter of the background disks (3.5° visual angle),
$L$ = luminance of the test disk,
$L_0$ = luminance of the background disks (33 cd/m$^2$),
$L_b$ = luminance of the dark part of the background (0.65 cd/m$^2$),
$C$ = contrast of the test disk relative to the background,
$C_{D0} = (D - D_0)/D_0$ ; $C_{L0} = (L - L_0)/L_0$ ; $C_{L_b} = (L - L_b)/L_b$,
$R$ = test disk eccentricity relative to the fixation spot,
$\bar{R}$ = size (averaged border eccentricity) of the effective visual field,
$\bar{R}_c$ = size of the conspicuity area,
$\bar{R}_d$ = size of the discrimination area,
$\bar{R}_v$ = size of the visibility area.

## 3.3. Influence of diameter

In this section we present experimental data concerning monocular conspicuity, discrimination and visibility areas as a function of the diameter of the test disk, for equal luminance of test and background disks : $L = L_0$.

3.3.1. *Experimental results*

For the two observers T.B. and F.E. the results obtained are plotted in fig. 3.4. The experimental data agree reasonably well for both observers. Of course $\bar{R}_c = \bar{R}_d = \bar{R}_v = 0$ applies to $D = 0$. Moreover, a minimum of $\bar{R}_c$ and $\bar{R}_d$ is found for $D$ approaching $D_0$, as expected since here one cannot distinguish the test disk from the background disks. The values of $\bar{R}_d$ compared to $\bar{R}_c$ are somewhat larger at all test disk diameters, which demonstrates the influence of foreknowledge of test disk location. For $D$ approaching $D_0$ the difference in size could hardly be perceived. However, detecting the presence of the test disk, with foreknowledge of location, was no problem. Accordingly $\bar{R}_v \neq 0$ for $D = D_0$ in fig. 3.4. With relatively large differences between $D$ and $D_0$, the values of $\bar{R}_d$ and $\bar{R}_v$ approximated to each other. The visibility of the test disk seemed there to be the limit of $\bar{R}_d$, since whenever the presence of the test disk could be detected, the difference in size was visually clear.

The relative minimum of $\bar{R}_v$ for $D$ approaching $D_0$ was not directly expected. The existence of such a minimum would be very interesting as an indication of specificity of interfering channels. We therefore checked the existence of this relative minimum by determination of the fraction of correct (detection) responses $P$ along the horizontal meridian of the temporal retina. The results obtained are depicted in fig. 3.5, where $P = 75\%$ is used as the visibility threshold value. The results of these verification experiments confirmed that the presence of the test disk with $D = D_0 = 3.5°$ visual angle could be perceived

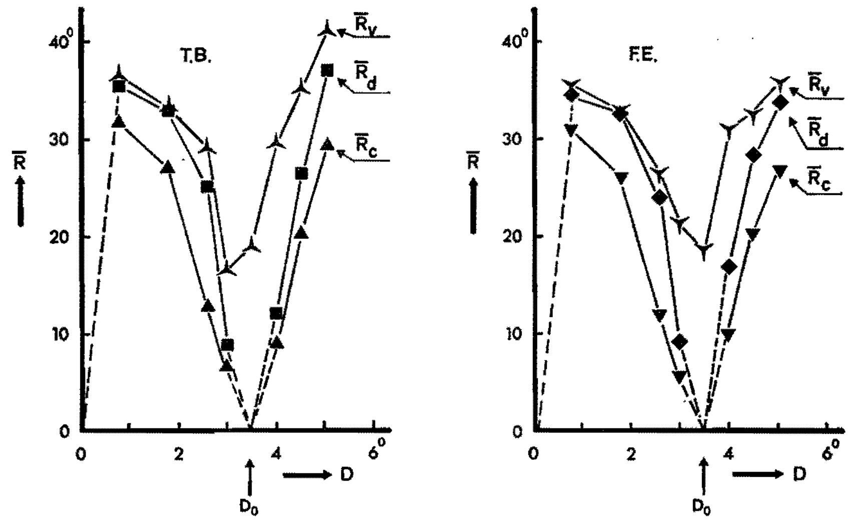



Fig. 3.4. Size of the conspicuity area ($\bar{R}_c$), discrimination area ($\bar{R}_d$) and visibility area ($\bar{R}_v$) as a function of the diameter ($D$) of the test disk in the complex background, for the observers T.B. and F.E.

less far from the fixation spot ($R \approx 35°$) than a test disk with $D = 0.8°$ or $D = 5.2°$ visual angle ($R \approx 50°$).

Finally, by means of the translucent sphere we determined the conspicuity and visibility area of the test disk on a plain background. In this situation there appeared to be no appreciable influence of foreknowledge of test disk location, since the conspicuity areas were identical with the visibility areas ($R_c \approx \bar{R}_v \approx 70°$)

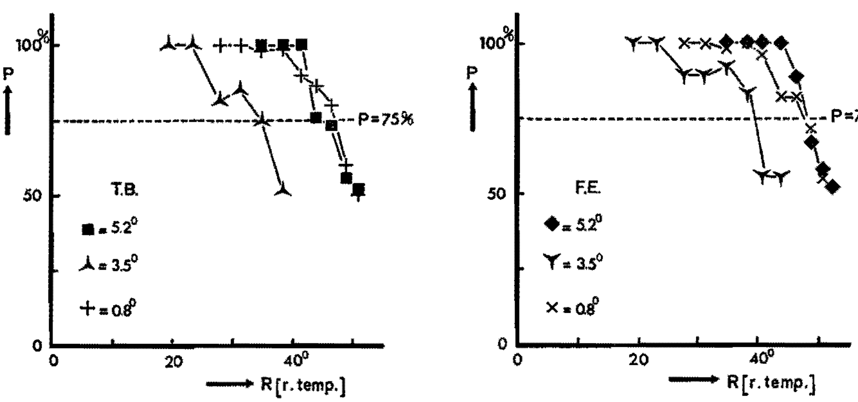



Fig. 3.5. Frequency $P$ of correct detection responses as a function of the eccentricity $R$ of the test disk in the complex background, along the horizontal meridian of the temporal retina. Each plotted point is based on 60 exposures. As followed from the threshold eccentricities ($P = 75\%$), the presence of the test disk with $D = 3.5°$ could be perceived less far from the fixation spot than the test disks with $D = 0.8°$ and $D = 5.2°$ visual angle.

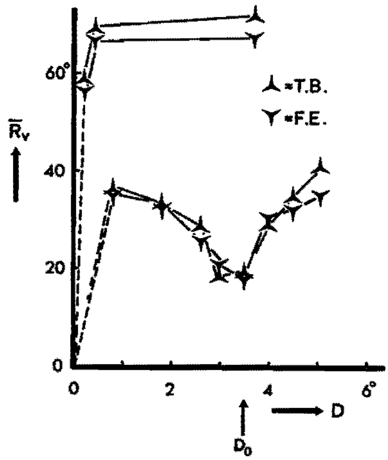



Fig. 3.6. Influence of background disks: the size $\bar{R}_v$ of the visibility area for the observers T.B. and F.E. as a function of the test disk diameter $D$, the lower curves with and the upper curves without the background disks.

and much larger than the corresponding areas for the test disk in the complex background. Figure 3.6 gives a direct comparison.

Since, furthermore, the rest field luminance in the plain background experiments also corresponded to the average test field luminance, the adaptation level (0.65 cd/m$^2$) was lower than in the complex background experiments (4.5 cd/m$^2$). A higher adaptation level would not change the general tendencies of the outcome: compared to the complex background results much larger visibility areas and of course no minimum of $\bar{R}_v$ near $D = D_0$.

3.3.2. *Introspection*

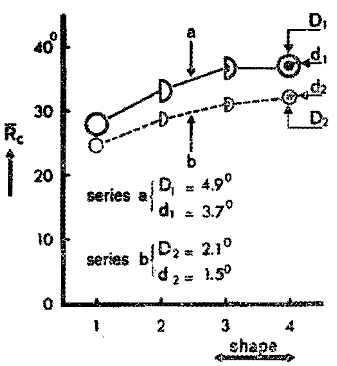
When the observer discovered the test disk near the border of the conspicuity area concerned, the perception of the test object was often incomplete. It occurred, for instance for large values of $D$ ($D > 3.5°$) that only a segment of the test disk was observed. Such observations were counted as positive responses. Sometimes, also the observer did not consciously perceive the test disk but, nevertheless, had a strong suspection of its location, which was often found to be correct. These cases were qualified as negative responses.

The threshold criterion maintained with the visibility area determinations was subjectively that the observer felt sure he perceived the presence of the test disk. Accordingly the nasal borders of the visibility areas corresponded to values of $P$ near 100% in the verification experiments. At $P$ values smaller than 100%, mainly faint differences in light distribution related to the presence or absence of the test disk, were used as guide for the conjectural responses of the observer. It occurred, for example for $D = 3.5°$, that the relatively dark gap in the background, remaining when the test disk was absent, was more perceptible than the presence of the test disk. So actually the observer decided here in favour of the presence of the test disk when he could not perceive its absence. Objectively it was not clear which physical variable actually determined the distinction of the test disk from the background disks. Possible candidates are diameter, area and contour length. Therefore some pilot experiments were performed with moon and ring shaped test objects in the complex background. These test objects were equal in outside diameter to the corresponding complete test disk but differed in area and contour length. Figure 3.7 gives the size of the conspicuity area for two series, series *a* with test objects larger and series *b* with test objects smaller in outside diameter than the surrounding background disks. The added table gives the test object data in more detail.

Note that, relative to the background disks, the difference in area is small for the test object with "shape 2a" ($\Delta A$ = —0.2 cm²), while the difference in contour lenght is small for "shape 4b" ($\Delta L$ = + 0.3 cm). It can be concluded from these data that factors not only related to outside diameter, but also to differences in "shape" played an important role here. As also subjectively it was not clear which property led to discovery of the test disk, we take in this paper the size, expressed by the test object diameter, to be the determining factor.

### 3.3.3. *Discussion*

As could be expected beforehand conspicuity and discrimination areas increased with increasing difference of $|D - D_0|$. It is of interest to note that $\bar{R}_c$ and $\bar{R}_d$ were found to be proportional to the logarithm of the "contrast in dia-




| Shape | A cm² | ΔA cm² | L cm | ΔL cm |
|---|---|---|---|---|
| 1a | 19 | 9.2 | 15 | 4.3 |
| 2a | 9.4 | —0.2 | 13 | 1.6 |
| 3a | 4.0 | —5.6 | 15 | 3.7 |
| 4a | 8.0 | —1.6 | 27 | 16 |
| 1b | 3.5 | —6.2 | 6.6 | —4.4 |
| 2b | 1.7 | —7.9 | 5.4 | —5.6 |
| 3b | 0.85 | —8.7 | 6.3 | —4.7 |
| 4b | 1.7 | —7.9 | 11 | 0.3 |

Fig. 3.7. Size $\bar{R}_c$ of the conspicuity area for different shapes of the test object in the complex background (averaged results of the observers T.B. and F.E.). Apparently these data are not readily explainable by a difference in outside diameter (*D*), area (*A*) or contour length (*L*) relative to the background disks.

meter": $C_{D_0} = (D - D_0)/D_0$. In formula these approximations are

$$\bar{R}_c = 39 \log 10 \left|C_{D_0}\right|,$$
$$\bar{R}_d = 40 \log 14 \left|C_{D_0}\right|.$$

Apparently the influence of foreknowledge of test disk location manifests itself here by a threshold change for $C_{D_0}$, which corresponds to a parallel shift of the approximating functions.

Extrapolating in fig. 3.8 our results to $\bar{R}_d = 0$, the foveal size discrimination threshold would correspond to $C_{D_0} = 0.07$ and thus for $D_0 = 3.5°$ to a difference in diameter $\Delta D = 15'$ visual angle. The same order of magnitude has been reported in literature. Ono [3-10] determined a value of 0.04 for the Weber-fraction for stimulus length. A similar value ($C_D = 0.03$) was obtained by Matthews [3-11] for 95% correct size discrimination between two adjacently presented luminous disks with $D = 50'$ and 1.5° centre to centre distance. According to his results size discrimination threshold (50%) increased about lineary with eccentricity of presentation, such that the difference in diameter was 10′ at $R = 10°$ and 30′ at $R = 30°$, which is roughly in line with peripheral acuity data of others (Westheimer [3-12], Sloan [3-13], Weymouth [3-14]). Size discrimination was less in our experiments: $\Delta D = 25'$ at $\bar{R}_d = 10°$ and $\Delta D = 1.4°$ at $\bar{R}_d = 30°$, which may be caused by the use of the complex background but also by difference in criterion and experimental circumstances.

In ophthalmology, the extent of the monocular visual field has been thoroughly investigated by means of perimetry (e.g. Dubois-Poulsen [3-8]). For high-contrast test disks a fast growth of $\bar{R}_v$ is generally obtained with increasing diameter of the test disk, up to approximately $D = 0.5°$ visual angle. Thereafter with increasing $D$, $\bar{R}_v$ levels off to about 70° visual angle. (Ferree and Rand [3-15]). This is in line with our plain background data of $\bar{R}_v$ in fig. 3.6.

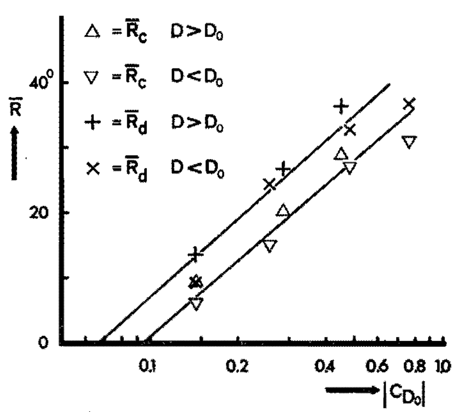



Fig. 3.8. Size of the conspicuity area ($\bar{R}_c$) and discrimination area ($\bar{R}_d$) as a function of the contrast in diameter $C_{D_0}$ on a logarithmic scale (averaged results of the observers T.B. and F.E.). Foreknowledge of test disk location manifests it self here by a shift in threshold for $C_{D_0}$.

Comparing our complex background visibility data with the plain background results (fig. 3.6), the interfering influence of the background disks becomes evident. Besides a general reduction of $\bar{R}_v$, the background disks also bring about a relative minimum of $\bar{R}_v$ near $D = D_0$. It seems therefore reasonable here to distinguish a diameter specific and a more general, non-diameter specific, interference component. The selectivity of the diameter specific component leads us to use the term "size-selective interference". The non-diameter specific component may result from several factors. As will be shown in sec. 3.4.2, the non-diameter specific component includes a luminance-selective factor. The limited resolving power of the eye can only play a minor role here. According to data collected by Le Grand [3-16]), the minimum angle of resolution at $R = 40°$ amounts to some 50′ visual angle, while the centre to centre distance of the test disk to the nearest background disk corresponds in our experiments to 8° visual angle (4.5° distance between the disk borders at $D = 3.5°$). The specific interactions apparently occur over large retinal distances, which argues against retinal processes. Dichoptic experiments may probably throw some light on this question.

## 3.4. Influence of luminance

In this section we present experiments on conspicuity, discrimination and visibility areas as a function of test disk luminance $L$. In these experiments the diameter of the test disk is equal to that of the background disks: $D = D_0$.

### 3.4.1. *Experimental results*

For the two observers T.B. and F.E., fig. 3.9 depicts the size of conspicuity, discrimination and visibility areas as a function of test disk luminance. Since the areas were obtained by applying filter foil to the test object on the slide, only data for $L \leqslant L_0$ are given. We expect that the functions will increase again for $L > L_0$, as happened in the case of $D > D_0$ in fig. 3.4.

It is self-evident that the conspicuity and the discrimination area become zero for $L = L_0$ and $L = L_b$ as does the visibility area for $L = L_b$ only. Dark-grey test disks ($L < 2$ cd/m$^2$) could be identified as such as soon as their presence could be detected, so $\bar{R}_d$ and $\bar{R}_v$ coïncided there. Foreknowledge of location was found there to be of little help, $\bar{R}_c$ being only slightly smaller than $\bar{R}_d$. For light-grey test disks ($L > 5$ cd/m$^2$) the three areas deviated much more from each other.

The decrease of $\bar{R}_v$ for $L$ approaching $L_0$ was again not directly expected. In order to verify this decrease in size of the visibility area, we determined the percentage of correct detection responses $P$ along the horizontal meridian of the temporal retina, see fig. 3.10. We also used $P = 75\%$ here as the visibility threshold value, as $P = 50\%$ was already obtainable by chance.

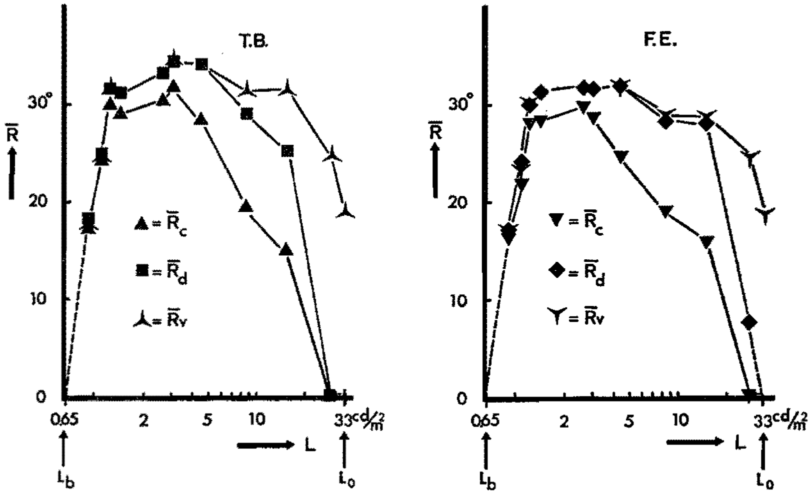



Fig. 3.9. Size of the conspicuity area ($\bar{R}_c$), the discrimination area ($\bar{R}_d$) and visibility area ($\bar{R}_v$) respectively as a function of the luminance $L$ (on a logarithmic scale) of the test disk with $D = D_0$ in the complex background, for the observers T.B. and F.E.

The results plotted in fig. 3.10 confirm that for $L$ approaching $L_0$ (33 cd/m²), the presence of the test disk in the complex background can be detected less far from the fixation spot than, e.g. for $L = 3.0$ cd/m².

For comparison we determined also on a plain background, the visual fields as a function of $L$, using the translucent sphere. With the plain background, again no appreciable influence of foreknowledge was observed, the conspicuity areas were equal to the visibility areas. The plain background visibility areas

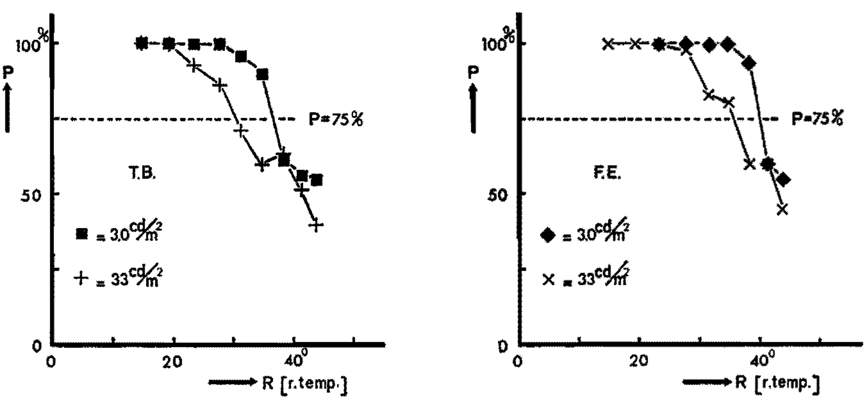



Fig. 3.10. Frequency $P$ of correct detection responses, based on 60 exposures for each plotted point, as a function of the eccentricity $R$ of the test disk in the complex background along the horizontal meridian of the temporal retina. As follows from the threshold eccentricities ($P = 75\,\%$), the presence of the test disk with $L = 3.0$ cd/m² could be detected further away from the fixation spot than the test disk with $L = 33$ cd/m².

were again much larger than the complex background visibility areas, see fig. 3.11.

The plain background results presented in fig. 3.11 are roughly in line with perimetric data supplied by others (e.g. Sloan [3-17]), Ferree and Rand [3-15])). Since the luminance of the rest field corresponded to the average luminance of the test field, here the rest-field luminance (0.65 cd/m²) was lower than in the complex background situation. However, choosing a higher adaptation level would not qualitatively alter our results: the existence of a general and a luminance specific decrease of $\bar{R}_v$ due to the introduction of the background disks.

### 3.4.2. *Discussion*

Visibility of the test disk is a prerequisite in discerning a luminance difference between the test disk and the background disks. Associated with that consideration one can roughly distinguish two parts in the plotted relation between $\bar{R}_d$ and $L$ in fig. 3.9. On the one hand a section for relatively high values of $L$ ($L > 5$ cd/m²), where discrimination areas are clearly smaller than the corresponding visibility areas and on the other a section for relatively low values of $L$ ($L < 2$ cd/m²) where both areas practically coincide. In the latter case, the visibility areas actually limited the discrimination areas as was also found to be the case introspectively: When the test disk was visible at these lower values of $L$, its dark-grey appearance was clear. Even the conspicuity areas nearly coincided here with the visibility areas, which implies that reserve is called for with regard to the circumstances under which directed attention influences the size of the visual field (Engel [3-1])). For higher values of $L$ the influence of foreknowl-

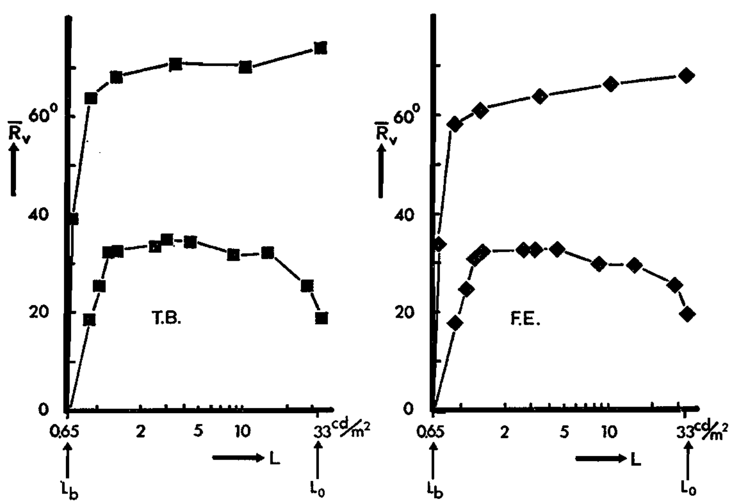



Fig. 3.11. Influence of background disks: size $\bar{R}_v$ of the visibility area as a function of the luminance $L$ of the test disk for the observers T.B. and F.E., the lower curves with and the upper curves without the background disks.

edge of test disk location was more apparent. For comparison with fig. 3.8, in fig. 3.12 $\bar{R}_c$ and $\bar{R}_d$ have been plotted for high values of $L$ as a function of $C_{L_0}$, the luminance contrast of the test disk relative to the background disks.

With $C_{L_0} = (L - L_0)/L_0$ on a logarithmic scale, again $\bar{R}_c$ and $\bar{R}_d$ could be reasonably approximated by linear functions. In formula these approximations are

$$\bar{R}_c = 78 \log 2.5 \left|C_{L_0}\right|,$$
$$\bar{R}_d = 41 \log 6.7 \left|C_{L_0}\right|.$$

In contrast to the results in fig. 3.8, where the influence of foreknowledge of test disk location manifested itself only in a threshold shift for $C_{D_0}$, the functions in fig. 3.12 showed a difference in slope as well. It follows from figs 3.8 and 3.12 that compared to $C_{D_0}$, factor changes in $C_{L_0}$ were about 2 times more effective with respect to $\bar{R}_c$.

When in fig. 3.11 we compare the complex background visibility data with the plain background results, the interfering influence of the background disks becomes again clear. Since one can expect that for the complex background situation $\bar{R}_v$ will increase again for $L > L_0$, as happened for $D > D_0$ in fig. 3.6 at least two components can be distinguished here also: a luminance-specific and a more general, non-luminance specific, interference factor. The selectivity of the luminance-specific component invited us here to use the term "luminance-selective interference". In view of the size-selective interference demonstrated for $D = D_0$ in sec. 3.3, we must conclude that the more general interference factor in fig. 3.11, where $D = D_0$, include a size-selective component. Similarly the non-diameter specific interference factor in fig. 3.6, where $L = L_0$, included in retrospect a luminance-selective component. So it must be

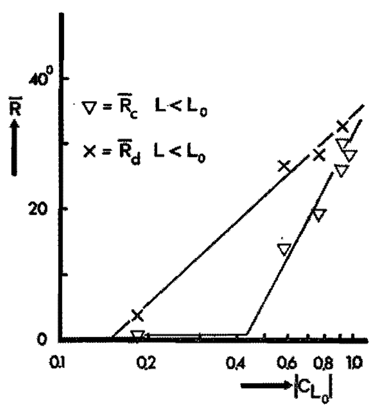



Fig. 3.12. Size of the conspicuity area ($\bar{R}_c$) and discrimination area ($\bar{R}_d$) as a function of contrast in luminance ($C_{L_0}$) of the test disk relative to the background disks on a logarithmic scale. The plotted points are averaged results of the observers T.B. and F.E.

emphasized that in spite of using an identical background, the general interference factors in figs 3.6 and 3.11 do not imply the same interaction. As the luminance-specific interferences also occurred over large retinal distances, one may expect the interaction to take place at a supra retinal level.

### 3.5. Combined influence

Now that we have separately described the size of the conspicuity area as a function of the diameter and luminance of the test disk, a following question is how both factors function together. In principle they will combine in some additive way as $\bar{R}_c = 0$ only when both $D = D_0$ and $L = L_0$. In this section we investigate this more closely. We restricted ourselves here to conspicuity areas only.

#### 3.5.1. *Experimental results*

Figure 3.13 gives $\bar{R}_c$ as a function of $L$ with the test disk diameter $D$ as parameter. For large differences in diameter compared to the background disks

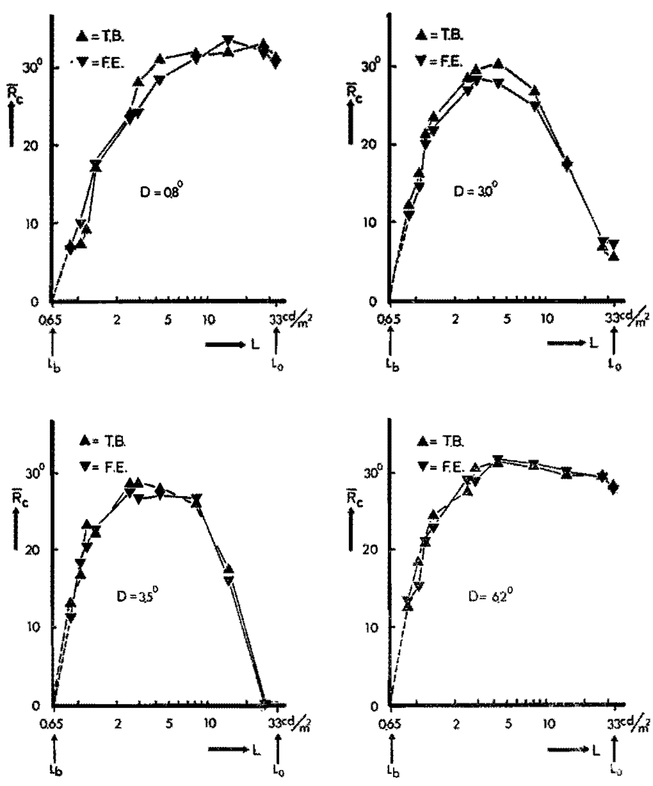



Fig. 3.13. Size $\bar{R}_c$ of the conspicuity area as a function of the luminance $L$ of the test disk with diameter $D$ for the observers T.B. and F.E. $D_0 = 3.5°$ visual angle; $L_0 = 33$ cd/m².

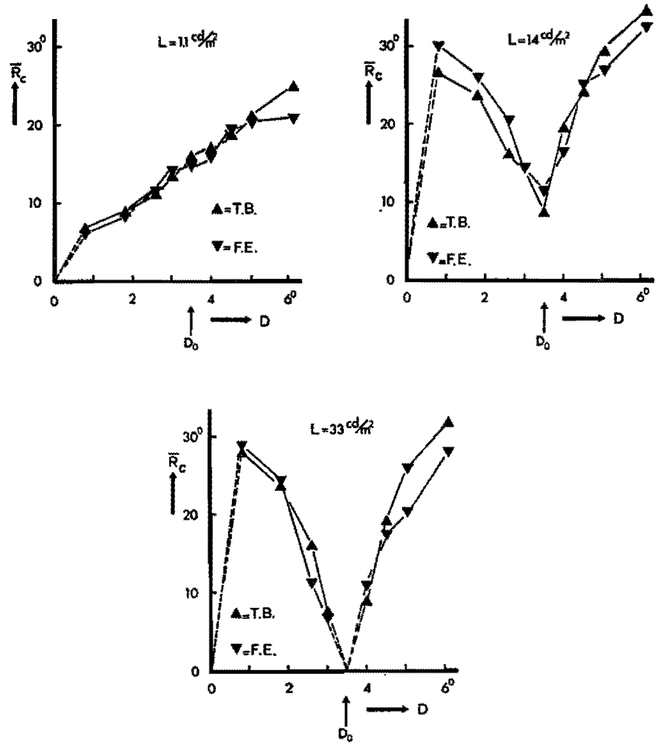



Fig. 3.14. Size $\bar{R}_c$ of the conspicuity area as a function of the diameter $D$ of the test disk with luminance $L$ for the observers T.B. and F.E. $L_0$ = 33 cd/m²; $D_0$ = 3.5° visual angle.

($D$ = 0.8° and $D$ = 6.2° visual angle), the influence of luminance contrast relative to $L_0$ was found to be small. Subjectively too, our impression was that here size contrast dominated the ease of finding the test disk. Figure 3.14 gives $\bar{R}_c$ as a function of $D$ with the test disk luminance $L$ as parameter. Similarly, fig. 3.14 indicates a decreased influence of size contrast with increasing luminance contrast relative to $L_0$. No relative minimum occurred near $D = D_0$ for $L$ = 1.1 cd/m².

### 3.5.2. *Discussion*

As can be concluded from our experimental results in sec. 3.5.1, the influences of the luminance- and size-contrast did not add up linearly with regard to $\bar{R}_c$. There exists, however, a complete family of distance ($d$) metrics, in formula

$$d = \{|d_x|^n + |d_y|^n\}^{1/n} \text{ with } n \geq 1,$$

e.g. as used by Shepard [3-18]) for the description of the additive structure in subjective dissimilarity. Depending on the values of $n$, these so-called Minkowski metrics range from linear algebraic summation for $n = 1$ towards logical summation known from Boolean algebra for $n \rightarrow \infty$. As a first approximation our results could be described in terms of a logical summation of the separate contrast effects. This means that the size of the conspicuity area was almost determined by the contrast factor with the largest effect. In figure 3.15 this approximation has been applied to the data given in figs 3.13 and 3.14, making use of the logarithmic type of approximations described earlier. Expressed as a formula this is

$$\bar{R}_c = 55 \log 3.6 \left|C_{L_0}\right| \oplus 29 \log 14 \left|C_{D_0}\right|,$$

where $\oplus$ stands for logical summation. The factors in this formula were obtained by adjustment to the data for $L = L_0$ and $D = D_0$ in fig. 3.15.

The influence of luminance contrast relative to the dark part in the complex background ($C_{L_b}$), becoming dominant for low values of $L$, can be approximated in fig. 3.15 by $\bar{R}_c = 25 \log 8.3 \left|C_{L_b}\right|$, but is, however, omitted, these for clearness sake.

The conspicuity areas for $L = L_0$ and $D = D_0$ presented in figs 3.13 and 3.14 were in general smaller than the corresponding areas in figs 3.9 and 3.4, as is also found from the different factors applied in the logarithmic approximations. Actually the former areas were determined about one year before the latter, during which several other experiments were carried out with the

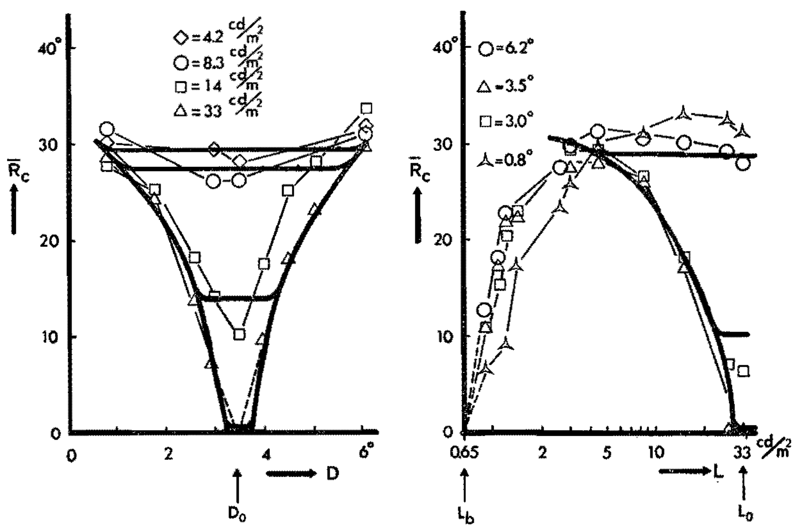



Fig. 3.15. Experimental results averaged over both observers, from fig. 3.14 and fig. 3.15 approximated by $\bar{R}_c = 55 \log 3.6 \left|C_{L_0}\right| \oplus 29 \log 14 \left|C_{D_0}\right|$. The factors in this formula were obtained by adjustment to $\bar{R}_c$ for $L = L_0$ and for $D = D_0$. Since $\left|C_{D_0}\right|$ was identical for $D = 6.2°$ and $D = 0.8°$ visual angle, only three horizontal branches are indicated in the righthand picture.

same complex background. In spite of short practice sessions before each area determination, training effects may be the reason for the increases in size. Accurate data on this subject cannot be given, however, since our experiments were not arranged for measuring the training effects systematically. Colquhoun and Edwards [3-19]) described training effects in the detection rates for the occasional presence of a slightly greater disk in displays of smaller disks. According to their evaluation the improvements were due to increases in discriminatory efficiency and not to changes in response criterion. This is in line with our impression that the observers learned to be increasingly sure of "irregularities" in the background as indications of the presence of the test disk. Johnston [3-20]), who related search time to peripheral visual acuity, also mentioned some papers related to practice effects in peripheral vision.

### 3.6. General discussion

In a previous paper (Engel [3-1])) we indicated that the conspicuity of objects can be assessed by means of the conspicuity area; within this retinal field the relevant object can be discovered from its background. Besides directed attention, limitations in peripheral visibility of the test object influenced the size of the corresponding conspicuity area in particular. However, with the somewhat arbitrarily chosen stimuli used at that time, the visibility area depended in some as yet unexplained way on the test object background combination applied. Therefore we used a test disk with variable diameter and luminance this time, in an environment of randomly located, identical background disks. With these stimuli we were able to specify the influences of the complex background more closely.

Considering the peripheral visibility of the test disk, we distinguished between the discrimination area, in which the difference between test object and background objects could be perceived, and the visibility area, in which the presence of the test object in the background could be observed; the test object location being indicated in advance in both cases. According to the test disk visibility data given in figs 3.6 and 3.11, the background disks caused size-as well as luminance-selective interference on the perceptibility of the test disk..

These interactions could not be understood simply on the basis of visual acuity, as they occurred over relatively large retinal distances (more than 8° visual angle). If we assume that the interferences reflect specificity of the interacting information channels, they constitute indications of the existence of size- and luminance-specific units. In fact, evidence for the existence of size- and orientation- selective neurons has been supplied initially by the work of Hubel and Wiesel [3-21, 22]), on single nerve cell recordings in the visual cortex of cat and monkey. It may be of interest to mention here, that orientation specific interference between straight lines in eccentric vision has also been established (Beerens and Bouma [3-23, 24]), Andriessen, Bouma and Beerens [3-25])). Indications for size- and orientation- selective processes has been provided moreover by measurement of evoked potentials due to grating patterns (Blakemore and Campbell [3–26]), Campbell and Maffei [3–27])). Selective adaptation effects also suggest the existence of mechanisms selective to line width (e.g. Gilinski [3–28]), Pantle and Sekuler [3–29]), May [3–30]), Weisstein and Bisaha [3–31])) and line length (Nakayama and Roberts [3–32])). Recently Kerr and Thomas [3–33]) also demonstrated in the case of disks with diameters ranging from 0.5 to 4° visual angle, size-selective adaptation effects in eccentric vision. To our knowledge, no luminance-selective adaptation effects have been reported in the literature. Our experiments do not exclude, however, the possibility of interference at a level where size and luminance specifity are combined.

Although other assumptions are conceivable, e.g. a signal to noise ratio consideration (Uttal [3–34])) or some confusion hypothesis, an attractive explanation for these selective interferences is that they are due to lateral inhibition effects between similarly tuned feature channels. According to this line of thought "irregularities" in the background would lead by some automatic means to relatively increased excitation of the corresponding channels. This assumption fits in with perceptual grouping or "Gestalt effects" (Wertheimer [3–35])) which occur as a function of object similarity (e.g. Beck [3–36])) and their spatial proximity (e.g. Zahn [3–37])). Indeed, influence of spatial proximity was also met with in pilot experiments we performed, in which decrease of disk density resulted in enlarged conspicuity areas. Furthermore, for very low densities (up to four objects) Greve [3–38]) observed no interferences at all in his experiments on multiple stimulus perimetry. Since our size- and luminance-selective interferences imply an emphasis of figure-ground relationships as early as the visibility stage, they support the idea of Neisser [3–39]) that certain global features of the input are already extracted by preattentive processes: *Wholistic operation which forms the units to which attention may then be directed, and which can directly control simple motor behavior.* Conspicuity as an external determinant of attention (Engel [3–1])) may then be conceived as relatively increased activity in certain feature channels which, consequently, may trigger selective attention.

Our size- and luminance-selective interferences may further have some links with metacontrast: the reduced perceptibility of a briefly presented visual target by a non-overlapping, preceding or succeeding visual stimulus. Of the many hypotheses on masking by metacontrast, proposed in the literature, two alternative interpretations are commonly emphasized, viz. the interruption and the integration hypothesis (e.g. see Kahneman [3–2])). The first assumes that further processing of the target is interfered or terminated by the after coming mask, while the second supposes that two stimuli following each other in rapid succession are effectively simultaneous. In line with earlier notions of Averbach and Coriell [3–40]), Turvey [3–41]) indicated that both hypotheses are probably true, as they presumedly describe visual masking at different processing levels. The integration hypothesis would then stress the interfering effect of the pattern mask on the sensory character of the target representation at a pre-attentive level, while the interruption hypothesis would stand for interference on the extraction of information, to be converted into some categorical form from the iconic target representation. Accordingly the integration hypothesis would fit in with our simultaneous interference effects, while perhaps the interruption hypothesis may have some relation to the difference in size between the conspicuity and discrimination areas. Bridgeman [3-42]) and Weisstein [3-43]) attempted to reconcile both notions of interference into a single mechanism, based on temporal effects of lateral inhibition.

Considering our conspicuity-area results, the size $\bar{R}_c$ of these areas increased, as expected, with contrast in luminance and diameter of the test disk relative to the background disks. If the test disk differed in both dimensions simultaneously, the size of the conspicuity area depended, as a first approximation, only on the predominant component, the contrast factor yielding separately the largest $\bar{R}_c$. This suggests that selective attention was attracted here by the predominant channel. This "dominance model" also applied to our conspicuity-area data on colour (Engel, Ligtenbarg and Bos [3-44])). The model also fits to search time data of Eriksen [3-45]), who found that location times for targets that differ in more than one dimension from other simultaneously presented objects, were not shorter than the constituting single-dimension location times. Directed attention as a result of foreknowledge of test disk location, generally increased the visual field ($\bar{R}_d$ being larger than $\bar{R}_c$ in figs 3.4 and 3.9), which is in line with earlier reports (Engel [3-1]), Grindley and Townsend [3-46])). However, this influence was not very pronounced for low values of $L$; the conspicuity area almost coïncided in this case with both the visibility and discrimination areas. Apparently the stimulus conditions under which directed attention influences the visual field need further investigation.

Summarizing, we derived the following conclusions from our experiments:

(a) For non-homogeneous backgrounds, the conspicuity of an object will mainly depend on restraining interactions from surrounding objects in the background.

(b) In our background of randomly located identical disks, these interferences in eccentric vision were at least size- and luminance-selective. We explained them by assuming lateral inhibitory effects between channels for similar features.

(c) Visual field determination seemed to represent an useful method for tracing the specificity of the interacting channels.

(d) The conspicuity area of test objects that differ in more than one dimension from the background objects could be described by a dominance model. According to this model, the contrast factor itself yielding the largest influence determined the size of the conspicuity area.

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# 4. VISUAL CONSPICUITY, VISUAL SEARCH AND FIXATION TENDENCIES OF THE EYE *)

**Abstract**

The cumulative probability of target discovery during search has been related experimentally to the relevant "conspicuity area", the visual field in which the target can be discovered after a single eye fixation. During search, "non-targets" were found to be fixated spontaneously in proportion to their conspicuity area. Further small spontaneous eye fluctuations are described that occurred, during determination of the conspicuity areas, in the direction of the target discovered. Their occurrence and delay depended on the target eccentricity and the size of the conspicuity area. The results emphasize the relevance of the conspicuity area to research on visual selection.

## 4.1. Introduction

In looking around, our eyes perform a first selection of the generally large amount of available visual information. This paper has to do with the intriguing question as to what factors determine the subject's choice of successive fixations. In particular we examined whether there is a relation between eye movements during search and visual conspicuity defined as the amount of prominence of a visual object in its surroundings.

Earlier we have investigated certain factors that influence visual selection during a single eye pause. We then namely considered external and internal determinants of selective attention; visual conspicuity was defined there as an external determinant (Engel [4–1]). We associated with each object in its background a so-called conspicuity area, the retinal field in which the object is capable of being noticed during a single eye pause, when the subject has no foreknowledge of its location. We proposed the size of this area as a measure of the conspicuity of the object in its particular background. If presented within this area, the object has been assumed to be capable of controlling selective attention by its visual conspicuity.

Since eye movements are generally regarded as bearing a relation to visual attention (e.g. Sanders [4–2]), Jeannerod, Gérin and Pernier [4–3]), Levy-Schoen[4–4]), Noton and Stark [4–5])), it seemed logical to investigate more closely the possible connections between visual conspicuity and eye movements. For that purpose eye movements were recorded during the performance of a number of visual search tasks. In these experiments the stimulus always consisted of a random dot pattern as background and two dissimilar disks as test objects, see fig. 4.1.

The observers were required to search for one specified test object, the "target", and to avoid fixation of the other test object irrelevant to the search task, the "non-target". By analysing the eye movements made, we were able to

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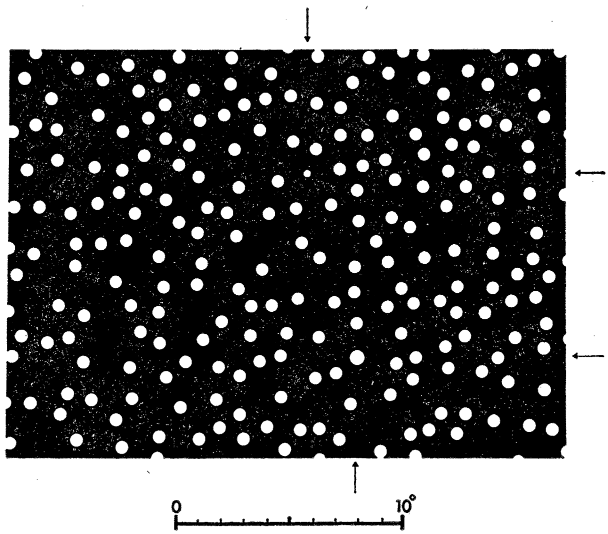


Fig. 4.1. Example of the stimulus material used. Besides the background disks, the pattern contains a smaller and a larger test disk. The arrows, pointing to their locations, are added for helping the reader to find them.

relate the visual conspicuities of the test objects to their probability of fixation under these two conditions.

In section 4.3 the conspicuity-area determinations are described, the results of which we needed for the evaluation of the search experiments. Here we discovered a new phenomenon. It was found namely that although strict fixation of the display centre was required, yet there frequently occurred a small spontaneous eye movement of about 0.7° visual angle in length, in the direction of the discovered target. Since the characteristics of these "target eye movements" supplied a new clue for understanding the way in which visual conspicuity influences eye movements and selective attention, some of their aspects are evaluated in sec. 4.4. In the first reading of this paper, however, sec. 4.4 may be passed over. In section 4.5 we relate the conspicuity-area data with the cumulative probability of discovering the target as a function of search time, while in sec. 4.6 we consider the tendency to fixation on the non-targets as a function of their conspicuity. Finally, in sec. 4.7 there is a general discussion including a tentative diagram of selective information reduction, which is intended to provide a framework for the experimental results obtained.

## 4.2. Experimental

### 4.2.1. *Stimuli and apparatus*

As already indicated in fig. 4.1 the stimuli in the search experiments consisted of randomly located background disks, all of them identical, on a dark ground and among them two different test disks. For the conspicuity-area determinations (sec. 4.3), however, the patterns only contained one test disk, the target. In the stimulus patterns overlapping of disks was prevented by maintaining a minimum centre-to-centre distance of 1.5 times the diameter of the background disks. The stimulus patterns were presented to the observer via a TV monitor screen. By shifting the field of view of the TV camera, one of the test objects, e.g. the target, could be located at any desired location on the screen, while the background pattern always completely filled the display. By doing so, new stimulus patterns became available, in which the configuration of background disks remained the same relative to the test object concerned. The observer was not much aided in his tasks by this fact, due to the random structure of the pattern.

Series of such stimulus patterns shifted each time, were prerecorded on a video tape. The patterns were separated in time by a plain rest field with a fixation cross in the centre. In the successive exposures the pattern was shifted in such a way that the relevant test object occupied in random sequence all the intersections of an imaginary grid across the monitor screen. In the conspicuity-area experiments of sec. 4.3 we used a circular grid with 50 intersections around the centre of the screen (fig. 4.2*a*). The grid size was roughly adapted to the expected size of the conspicuity area concerned. In the search experiments of secs 4.5 and 4.6, we used a rectangular grid with 6×8 intersections that covered the whole display (fig. 4.2*b*).

In the search experiments, where two test objects were always presented simultaneously, only the first was positioned precisely on the selected inter-

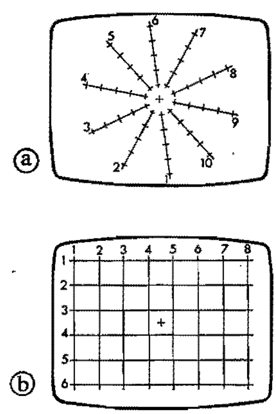


Fig. 4.2. (*a*) In the conspicuity-area experiments the target object occupied in random sequence all the intersections of the indicated circular grid, the size of which has been adapted roughly to the expected size of the conspicuity areas concerned. (*b*) In the search experiments a rectangular grid covering the whole display has been used. Therefore the probability of test object appearance was roughly constant over the screen.

section by alignment of the camera. In view of the requirement of a minimum distance between objects, the location of the second test object, determined by a different random sequence, was at the position of the background disk nearest to the selected intersection. As the prerecorded stimulus series were presented more than once to the same observer, each series started with five extra stimulus patterns, used as dummies. Besides serving to warm up the observer, they decreased the possible influence of acquired knowledge concerning the first few target locations.

By means of 1 second clock impulses recorded in advance on one of the sound tracks, and with the picture-insert facility of the video tape recorder (Sony 320CE), that did not erase these clock impulses during recording, we were able to program the successive stimulus pattern durations in 1 second multiples. The insert facility on the tape recorder supplied smooth joints between the successive pictures. Figure 4.3 gives an outline of the set-up for recording the stimuli.

The durations of the stimulus fields were 1 s each for the conspicuity-area determinations (sec. 4.3), while they were 4 s each in the search experiments (secs 4.5 and 4.6). The rest field durations were always 1 s each. The density of background disks was not changed, therefore the stimulus patterns always contained some 220 background disks. At the maintained viewing distance of 57 cm, the dimensions of the TV screen corresponded to $22.3 \times 16.8°$ of visual angle, while the diameter of the background disks on the TV screen resulted in a visual angle of 0.55°. As test objects we used disks with diameters corresponding to the following visual angles on the monitor screen; 0.34°, 0.45°, 0.63° and 0.69°. These values were chosen such as to ensure a suitable range of conspicuity-area sizes.

For all disks the luminance was 11.5 cd/m$^2$, while it amounted to 0.45 cd/m$^2$ for the dark ground and 0.34 cd/m$^2$ for the plain rest fields. The luminances were measured at the centre of the TV screen and at the eye position of the

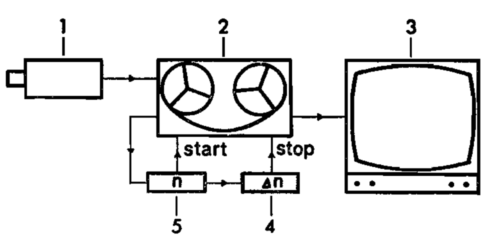


Fig. 4.3. Set-up for recording the stimulus material. During playback, clock impulses are counted up to an adjustable number ($n$), after which the video recorder is electronically switched into the insert mode, so that a new picture is recorded for $\Delta n$ seconds. 1 = TV camera; 2 = video tape recorder; 3 = TV monitor; 4 and 5 = adjustable pulse counter.

observer. Due to "vignetting" of the TV tube, all screen luminances gradually decreased towards the borders by some 15%. Since the test disks were distinguished from the background by differences in diameter, this shortcoming was considered to be of minor importance for the findings to be presented.

The eye movements were measured by means of the cornea-reflection technique (e.g. Mackworth and Mackworth [4–6]). Figure 4.4 gives an outline of the set-up that we used.

Although vision was binocular, only movements of the observer's left eye were recorded. This was done by directing a near infrared light beam ($\lambda > 770$ nm) towards the left eye. This light was invisible to the observer, not however to the infrared-sensitive Silicon-Vidicon camera tube on which the reflected beam from the cornea was focussed. The signal of said camera 1 was electronically mixed with that of camera 2 viewing the stimuli on monitor 9. After suitable calibration we were able to match both TV signals in such a way that the position of the cornea-reflection spot almost coincided with the observer's fixation point. Systematic deviations between both locations remained within 1° of visual angle, the largest deviation occurring at the corners of the $22.3 \times 16.8°$ monitor screen. By means of the obligatory fixations on the display centre, during the rest field presentations in between the stimulus fields, the measurements were corrected every 5 s for the possible occurrence of drift due

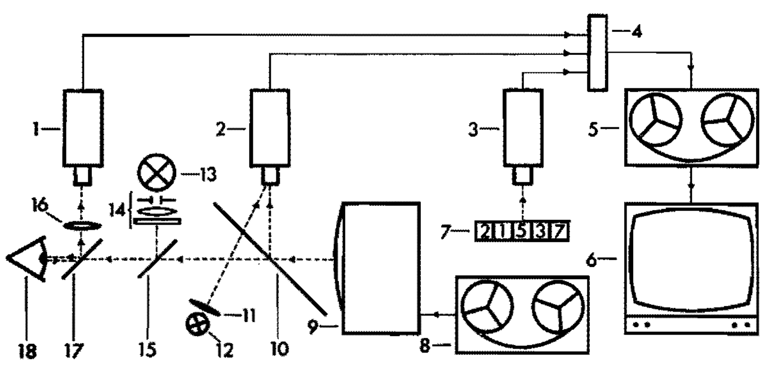


Fig. 4.4. Set-up for presentation of the stimulus material and for measurement of eye movements by means of the cornea-reflection technique: 1 = TV camera for recording the infrared cornea-reflection spot; 2 = TV camera for simultaneous recording of the stimuli presented; 3 = TV camera for registration of the field numbers, for timing purposes; 4 = video mixer; 5 = video tape recorder for the overlapping registration of the scene presented, the position of the cornea-reflection spot and the field number; 6 = monitor screen of the experimenter; 7 = number display, triggered by the vertical synchronisation signal of the TV cameras; 8 = video tape recorder for presentation of the stimulus material; 9 = TV monitor for presentation of the stimuli to the observer; 10 = semi-reflecting mirror; 11 = lens; 12 = signal light to be controlled by the observer; 13 = light source for generation of the cornea-reflection spot; 14 = diaphragm, infrared filter and lens; 15 = semi-reflecting mirror; 16 = lens; 17 = semi-reflecting mirror; 18 = the observers' eye.

to small remnants of head movements. We tried to eliminate these head movements, by using a forehead rest and a bite board with a dental cast of the observer concerned. Moreover, much help was obtained from a back-head rest, thanks to which the observer was not required to clench his teeth on the bite board consistently. He could "hang" by his upper jaw and the back of his head, thus preventing lock-jaw.

For identification and timing purposes, the successive TV fields to be recorded were labeled in the lower left corner with a serial number. This was done by focussing camera 3 on the digital L.E.D. display of a pulse counter that was triggered by the vertical synchronisation signal of the TV cameras. The TV system enabled us to sample the eye movements in 20 ms intervals. A pushbutton enabled the observer to indicate the discovery of the target in the stimulus fields. This button controlled a small light signal that became optically mixed with the image from monitor 9 and so further inserted into the eye movement recordings, see fig. 4.4.

### 4.2.2. *Observers*

The experimental data to be presented were obtained from the observers T.B. and F.E. Both were experienced observers with adequate vision without spectacles. They had natural teeth, which was important in view of the use of the bite board, for reliable measurement of the eye movements. All experiments reported were repeated by at least one inexperienced observer, being not always the same one, however. Their results were almost similar to the data to be reported.

### 4.2.3. *Terminology*

$D$ = diameter test disk (ranging from 0.34° to 0.69° of visual angle),
$D_0$ = diameter background disks (0.55° of visual angle),
$A$ = area of the display (22.3°×16.8° of visual angle),
$L$ = length of eye saccade,
$N$ = number of events,
$n$ = cumulative number,
$P_{cd}$ = cumulative probability of fixation, respectively of discovery,
$P_d$ = proportion of discovered targets at a given eccentricity,
$P_t$ = proportion of target eye movements for target presentation at a given eccentricity,
$P_f$ = proportion of free eye movements for target presentation at a given eccentricity,
$P_1$ = single fixation probability of test object discovery,
$P_N$ = probability of target discovery at the $N$th fixation,
$P(t)$ = probability of target discovery as a function of time,
$R$ = retinal eccentricity of target presentation,

$\bar{R}_{50}$ = size (average radius) of the conspicuity area at 50% threshold level,
$R^*$ = normalized eccentricity = $R/\bar{R}_{50}$,
$\varrho$ = effective size of the relevant conspicuity area during search,
$t$ = (search) time,
$\bar{t}$ = average search time,
$T_{fix}$ = fixation duration, including duration of the corresponding saccade,
$\Delta T_t$ = delay time between stimulus onset and target eye movement,
$\Delta T_f$ = delay time between stimulus onset and free eye movement,
$\Delta T_s$ = delay time between stimulus onset and the manual light-signal response.

### 4.3. Conspicuity-area determinations

In the experiments to be described in this section, the observer was instructed not to move his eyes. He had to fixate a small continuously visible cross in the centre of the screen and when the stimulus pattern appeared, to indicate with the push-button switch if he discovered the target object. After finishing a complete series of stimulus patterns, in which the same target object appeared in random sequence once on each of the 50 intersections of the imaginary circular grid (fig. 4.2*a*) around the fixation cross, the extent of the corresponding binocular conspicuity area was obtained. For improvement of reliability each series has been displayed 4 times to each of the observers.

As we aimed at relating the conspicuity-area results to the search experiments to be described in secs 4.5 and 4.6, the conspicuity area determinations were performed in the same cornea-reflection set-up. This procedure moreover offered the possibility of gaining information about the accuracy of fixation.

#### 4.3.1. *Experimental results*

Figure 4.5 gives for both observers the averaged proportion $P_d$ of targets discovered, as a function of the eccentricity $R$ of target presentation. The 100% level in fig. 4.5 corresponds to 40 target discoveries, since each stimulus series with 10 target presentations at the same eccentricity (fig. 4.2*a*) has been displayed 4 times.

The eccentricity at which 50% of the targets, presented in ten directions, were discovered, has been taken as the size ($\bar{R}_{50}$) of the (binocular) conspicuity area. Figure 4.6*a* gives values of $\bar{R}_{50}$, calculated by means of linear regression technique from the relevant data points in fig. 4.5. In figure 4.6*b* these values are plotted against the absolute difference in diameter between the target and the background disks.

#### 4.3.2. *Discussion*

As indicated in fig. 4.6*b*, the size $\bar{R}_{50}$ of the binocular conspicuity area increases about linearly with the absolute difference in diameter between target disk and background disks. Taking into account the relatively small range of

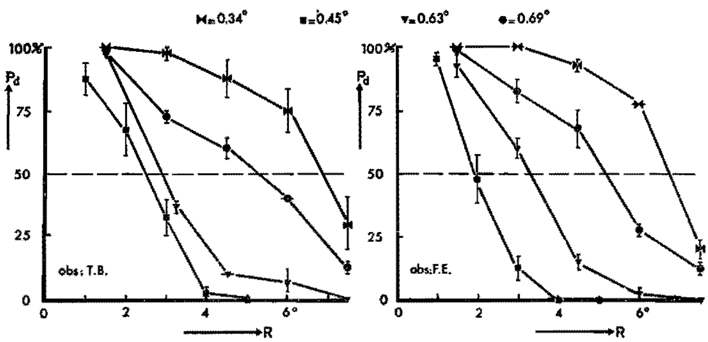


Fig. 4.5. The proportion ($P_d$) of discovered targets as a function of the eccentricity ($R$) of their presentation relative to the central fixation cross, for two observers (T.B. and F.E.). The diameter ($D$) of the target disk has been taken as parameter. The diameter of the background disks $D_o = 0.55°$ of visual angle. The vertical bars indicate the experimental estimate of the standard error of the mean. The omission of such a bar at certain data points (e.g. for obs. T.B. at $R = 6°$ for $D = 0.69°$) indicates that the estimated standard error equals zero.

(a)

| D = | 0.34° | 0.45° | 0.63° | 0.69° | observer |
|---|---|---|---|---|---|
| $\bar{R}_{50}$= | 6.8° | 2.4° | 3.2° | 5.0° | T.B. |
| $\bar{R}_{50}$= | 6.5° | 2.0° | 3.4° | 5.1° | F.E. |

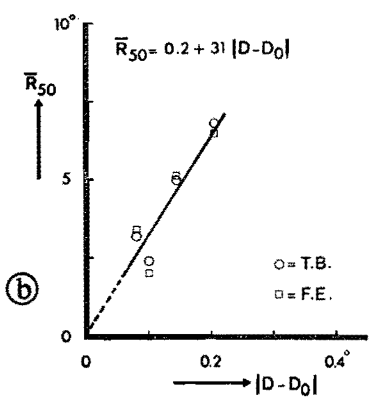


Fig. 4.6. ($a$) The size ($\bar{R}_{50}$) of the binocular conspicuity area for different target diameters ($D$); $D_o = 0.55°$ of visual angle. ($b$) The size ($\bar{R}_{50}$) of the conspicuity area against the absolute difference $|D - D_o|$ in diameter between the target and background disks. The relation can be approximated by the indicated linear regression function.

diameter differences used, this result is qualitatively in line with the data of earlier monocular conspicuity-area determinations (Engel [4–7]). There namely, over a much larger range of diameter differences, we fitted the data to a logarithmic function of the "contrast" in diameter [$\log |(D - D_0)/D_0|$]. The data do not quantitatively agree, however, probably because of a difference in experimental circumstances. For instance, in the earlier experiments the background disks were much larger ($D_0 = 3.5°$). The other factors that possibly contributed to this discrepancy were the differences in exposure time and in the luminances applied, while in contrast to the earlier monocular presentations the stimuli were now presented binocularly.

Due to the simultaneous measurement of eye movements during which speaking was impossible, the observer had to respond with the signal light only. Therefore we had no direct check on the correctness of the responses obtained. We accepted this shortcoming, since the reproducibility of the results was reasonable; in fig. 4.5 the vertical lines through the data points indicate the standard errors of the means. The rather extended transition regions depicted in fig. 4.5 mainly result from the generally non-circular shape of the conspicuity areas (see e.g. Engel [4–1]).

During the brief (80 ms) stimulus exposures of earlier conspicuity-area determinations (Engel [4–1,7]) practically no eye movements occurred. However, during the longer (1 s) exposures used this time, a small to-and-fro eye movement was frequently observed in the direction of the target discovered. In the following sec. 4.4, we shall go somewhat further into the properties of these small "spontaneous" eye movements, since they depend on the conspicuity of the target used. As mentioned earlier, sec. 4.4 may be passed over in the first reading, its essence being the finding that the occurrence and corresponding delay of these eye movements depended on the target eccentricity and the size of the corresponding conspicuity area.

### 4.4. Spontaneous eye movements

Although our observers did their best to maintain fixation on the marked centre of the screen, nevertheless rather freqently a small spontaneous eye movement occurred some 400 ms after onset of the stimulus pattern, mostly in the target direction. Usually this spontaneous saccade was followed about 200 ms later by a second small movement back to the fixation centre. If the first saccade was in the target direction, we called it a "target eye movement", we named it on the other hand a "free eye movement" if it occurred in an other direction. The target eye movements, with an average length of about 0.7° of visual angle, were too short to reach the target. Nearly all target eye movements were followed roughly 300 ms later by the light signal, indicating the discovery of the target.

Most times our observers were unconscious of their spontaneous eye movements. As far as they were aware they felt that they had made a target eye movement before they realized it. As a typical example, characteristics of such spontaneous eye movements are given in fig. 4.7 for one experimental situation. In view of the newness of this phenomenon, the graphs given in fig. 4.7 will be considered more extensively in this section, together with other relevant data.

### 4.4.1. *Occurrence*

As a function of target eccentricity fig. 4.7*a* gives the proportion ($P_t$) of target eye movements and the proportion ($P_f$) of free eye movements that occurred. The 100% level corresponds to 40, this being the number of target presentations at the eccentricity concerned. The eye movements have been classified according to their direction of movement around the fixation spot. Movements deviating less than 18° from the true target direction were considered to be "target eye movements", the others were taken to be "free eye movements".

The chosen value of plus or minus 18° corresponded to the division of the circular grid (fig. 4.2*a*), which facilitated the read-out of the recordings. Moreover, it prevented distortion of our results due to the occurrence of deviations in eye movement direction, which appeared to depend systematically on the direction of target presentation. Movements in the top right or left directions for instance, were frequently rotated somewhat counter clockwise, while downward movements were often slightly rotated clockwise. These systematic changes in direction fit in with the curvatures of saccadic eye movements described by Thomas and O'Beirne [4–8]) as a function of saccadic direction. They suggested that these curvatures, which were also found in our eye movement recordings, are due to a non-simultaneous innervation of the extra-ocular muscles. Although matching of the cornea-reflection spot with the fixation cross was not always perfect, the fluctuations of the eye could be detected relatively easily. Especially the spontaneous eye movements deviated in dynamic aspects from the slower movements, e.g. of respiration. The structure of the overlapping stimulus pattern also facilitated the detection of these movements. Repeated read-out indicated that our detection of these eye movements was reliable. A relation appeared to exist between the occurrence of these target eye movements and the discovery of the target. To illustrate this, the relevant conspicuity-area data from fig. 4.5 has been redrawn in fig. 4.7*a*. In fact, in 90% of the times that such a target eye movement occurred, the signal light switched on some 300 ms later, indicating the conscious discovery of the target object. The relation between $P_d$ and $P_t$ is more fully apparent in fig. 4.8, where we plotted all conspicuity-area data, as given in fig. 4.5, as well as the fractions of occurrence of the corresponding target eye movements, against the normalized eccentricity:

$$R^* = R/\bar{R}_{50} \tag{4.1}$$

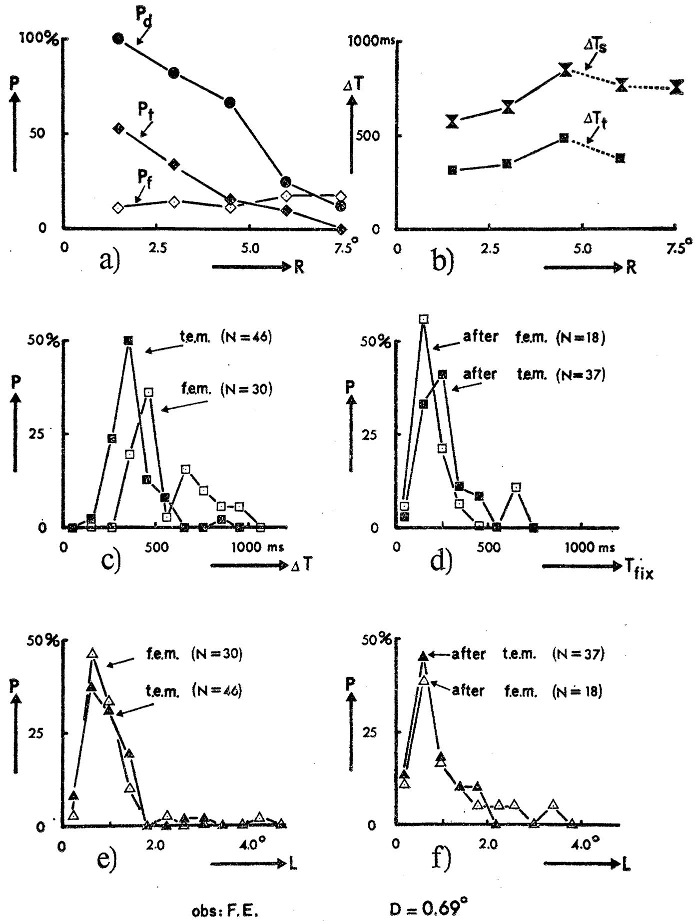


Fig. 4.7. Typical characteristics of the spontaneous eye movements made by F.E. in the 0.69° target situation. (*a*) Proportion ($P$) of occurrence of spontaneous eye movements in percentage of the total number (40) of targets, presented at the indicated eccentricity $R$. $P_t$ concerns target eye movements while $P_f$ concerns free eye movements. For comparison purposes, $P_d$, the proportion of discovered targets (from fig. 4.5) has also been plotted.

(*b*) The delay time $\Delta T_t$ between stimulus onset and target eye movement and the delay time $\Delta T_s$ between stimulus onset and the light-signal response of the observer against the retinal eccentricity ($R$) of target presentation. The results at $R = 6°$ and $R = 7.5°$ of visual angle are not very reliable in view of the paucity of events at these eccentricities (see $P_t$ and $P_d$ in fig. 4.7*a*).

(*c*) Frequency polygons of the delay time before occurrence of a target eye movement (t.e.m.) and before occurrence of a free eye movement (f.e.m.), $N$ indicates the total number of events.

(*d*) Frequency polygons of the eccentric fixation duration ($T_{fix}$) after target and free eye movements.

(*e*) Frequency polygons of the length ($L$) of the target and free eye movements away from the centre.

(*f*) Frequency polygons of the saccade lengths ($L$) towards the centre after target and free eye movements respectively.

The fractional normalization supplied a better mutual fit of the data for the different test objects than a normalization according to $(R - \bar{R}_{50})$. This corroborates the suggestion given in sec. 4.3.2, that the relatively large transition regions in fig. 4.5 are mainly due to the non-circular shape of the conspicuity areas. Namely, if we assume an approximatively unchanged shape with increase in size, i.e. a constant ratio of the smallest to the largest threshold eccentricity, it can be shown by means of the similar triangles in fig. 4.9, that the transition region increases in proportion to the size of the conspicuity area, so that here a fractional normalization meets our needs.

According to a first order approximation, as given by the linear regression lines and the corresponding equations in fig. 4.8, these target eye movements

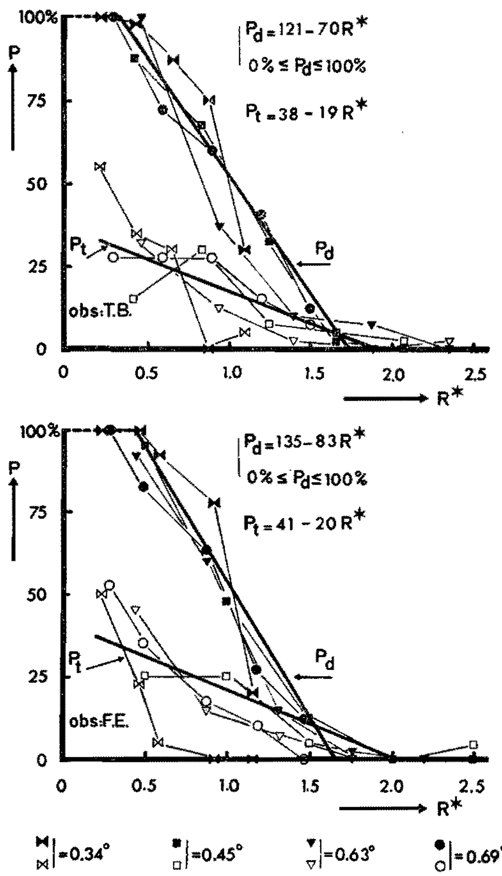


Fig. 4.8. As a function of the normalized eccentricity $R^*$, the proportion of discovered targets ($P_d$) and the proportion ($P_t$) of target eye movements. Linear regression lines have been drawn to indicate their relationship. The coefficients of the corresponding equations have been truncated in accordance with their statistical reliability.

occurred in the case of our two observers in about 30 to 40% of the times that the test object was discovered.

As to the free eye movements, their proportion of occurrence ($P_f$) appeared to be rather low and independent of the eccentricity of test object presentation, see fig. 4.7*a*. Perhaps they were related to certain background objects, which were sometimes presented quite close to the fixation centre. We could not find a systematic origin, however, except that they were related in time to the onset of the stimulus pattern (fig. 4.7*c*).

4.4.2. *Delays*

In fig. 4.7*b* we plotted against target eccentricity $R$, the delay $\Delta T_t$ between stimulus onset and target eye movement and the delay $\Delta T_s$ between stimulus onset and the light signal response. Both delays increased with $R$, the difference between them being almost constant. In relation to fig. 4.7*b* it should be remarked that the indicated delay times at $R = 6.0°$ and $R = 7.5°$ of visual angle are less reliable because of the small number of events (see fig. 4.7*a*) over which an average has been taken. Virtually all our delay time data showed the

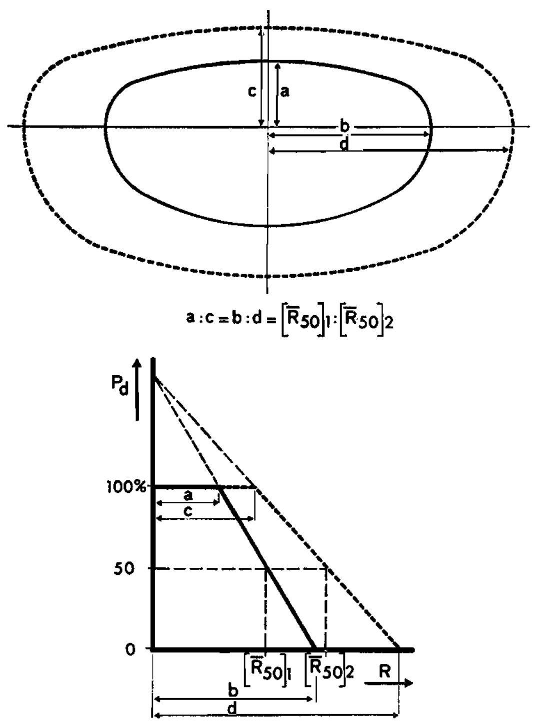


Fig. 4.9. Assuming that the ratio of the smallest to the largest eccentricity of the conspicuity area remains similar with increase in size ($a : c = b : d$), see the upper drawing, it follows that the corresponding borders can be approached by straight lines intersecting the $P_d$-axis at the same point, see the lower drawing. It implies that these lines can be normalized through $R^* = R/\bar{R}_{50}$.

two mentioned tendencies. Moreover, the increase with $R$ appeared to depend on the size $\bar{R}_{50}$ of the conspicuity area concerned, larger areas giving, on the whole, shorter delay times as well as smaller increases with $R$. These effects could be summarized by plotting them against $R^* = R/\bar{R}_{50}$ (fig. 4.10). The overall linear regression lines plotted through the data in fig. 4.10 stress the increase in delay with $R^*$ and the constant difference of 250 ms for T.B. and 300 ms for F.E. between $\Delta T_s$ and $\Delta T_t$.

The results presented needed no further correction for the inherent opto-electronic delay of the TV camera system, since all three signals (the stimulus onset, $\Delta T_t$ and $\Delta T_s$) appeared to be delayed about equally, viz. the duration of one TV field (20 ms).

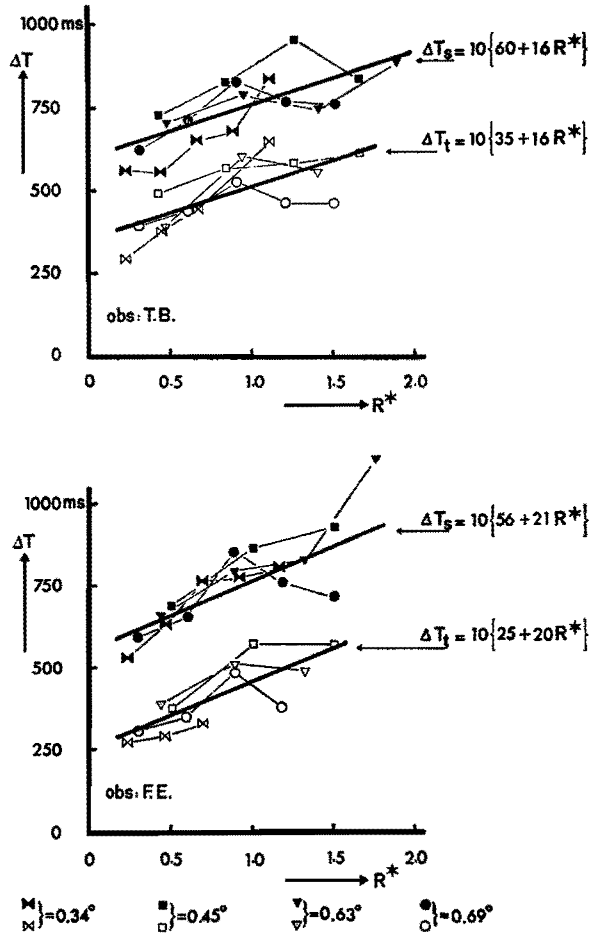


Fig. 4.10. The delay time $\Delta T_t$, before occurrence of a target eye movement, and the delay time $\Delta T_s$ before occurrence of the observers response with the light signal, plotted against the normalized eccentricity $R^*$. The overall linear regression lines plotted emphasize: (1) the increase in delay with $R^*$ and (2) the constant difference between $\Delta T_s$ and $\Delta T_t$.

It should be noted that the $\Delta T_s$ values are not regular reaction times because we did not explicitly ask the observers to control the light signal as fast as possible. However, we do not believe the difference to be large in practice since the experimental set-up forced them to react rapidly in order to be in time for the next stimulus presentation.

Two hypotheses are conceivable as to the nearly constant difference in delay time between the onset of a target eye movement and that of the corresponding manual light response signal. The first is that both motor actions are initiated at the level of target recognition, so that the difference in delay would be the result of a difference in transition time. The second is that the target eye movement had been initiated already at the moment that the target triggered selective attention (see also fig. 4.19) and that the pushbutton action started after target recognition, which is supposed to occur later. In view of the relatively large difference in delay, we consider the second hypothesis to be more credible. This would imply that $\Delta T_t$ relates to the conspicuity of the target object, as will be later shown to be the case indeed (fig. 4.11).

An outstanding aspect of our delay-time data is their relatively large increase with increasing $R^*$. For instance, in fig. 4.10 for F.E., $\Delta T_t$ increases about 250 ms in the transition region approximately lying between $R^* = 0.4$ and $R^* = 1.6$ (see fig. 4.8), which corresponded for $\bar{R}_{50} = 2.0°$ (observer F.E., $D = 0.45°$) to a difference in eccentricity of 2.4° of visual angle only. Since the conspicuity areas are non-circular in general, even sharper increases in delay time are to be expected for single direction data. The data in fig. 4.10 namely represent results obtained by averaging over 10 directions. The small amount of data available for each direction separately does not allow us, however, to check this point reliably now. Schiepers [4–9]), who investigated word recognition in eccentric vision found a comparable value, viz. 150 ms/degree of visual angle, for the increase in vocal response latency against eccentricity of word presentation.

The increase in delay time, reported in the literature as a function of the retinal eccentricity for single objects on plain backgrounds are much smaller. Bartz [4–10]) reported, for instance, for a 30° difference in eccentricity about 50 ms difference in eye movement latency, while regular pushbutton reaction times yielded on the average some 30 ms difference for a 30° difference in eccentricity with respect to the fovea (Rains [4–11]), Paine [4–12])). The authors used isolated objects with luminance-contrast values well above threshold. In view of the results of our earlier work (Engel [4–1,7])), it may be assumed that these isolated objects possessed relatively large conspicuity areas, so that their object presentations were of course located within the corresponding conspicuity areas. Our data can then be taken to agree with their results, since the predicted increase in delay time from 0 towards $R^* = 0.4$, obtainable by extrapolation of the regression lines in fig. 4.10, is at most about 80 ms. For 6°-horizontal target steps, as a function of target luminance and contrast, Wheeless, Cohen and

Boynton [4-13]) found the saccadic reaction time to vary from about 450 ms at threshold level to about 250 ms for much higher levels. Their data roughly correspond to our delay times found for the transition region.

Let us now consider fig. 4.7*c*, where we have plotted separately for target and free eye movements the frequency polygons of the time lapse $\Delta T$ between the stimulus onset and the moment of occurrence of these eye movements. The target eye movements occurred on average earlier than free eye movements. All our results showed this tendency significantly. Moreover, as already touched upon in relation to fig. 4.10, the mean over the transition region obtained $\Delta T_t$ values for target eye movements decreased with increasing $\bar{R}_{50}$. In fig. 4.11 this is shown by plotting the arithmetic mean ($\Delta \bar{T}_t$) of that delay against $\bar{R}_{50}$. In connection with the flow diagram in sec. 4.7.2, we shall there propose an explanation for the decreasing $\Delta T_t$ with increasing $\bar{R}_{50}$ and decreasing $R^*$.

No significant dependence of the mean delay $\Delta \bar{T}_f$ on $\bar{R}_{50}$ was found for the free eye movements. For these movements $\Delta \bar{T}_f$ equalled about 0.52 s, which is relatively long compared to the values obtained for target eye movements (fig. 4.11).

### 4.4.3. *Corrective actions*

Frequency polygons for the off-centre fixation durations ($T_{fix}$), following the target and free eye movements are given separately in fig. 4.7*d*. The means of these polygons neither differed significantly from each other, nor from the values obtained with the other target objects. For T.B. the averaged $T_{fix}$ amounted 0.34 s, for F.E. this was 0.21 s. These values are in general smaller than the $\Delta T_t$ values mentioned in sec. 4.4.2, which is perhaps a result of foreknowledge with respect to the location of the display centre. Another interpretation is that the target eye movements are the result of a difference in time

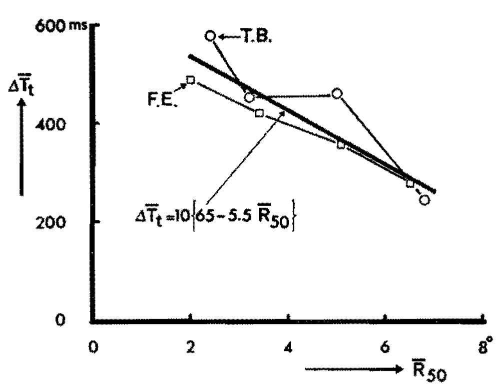


Fig. 4.11. The arithmetic mean ($\Delta \bar{T}_t$) of the delay times before occurrence of a target eye movement, against the size ($\bar{R}_{50}$) of the corresponding conspicuity area.

of arrival of the command for a spontaneous target eye movement and a reaction command both for interrupting and correcting the undesired movement. The latter interpretation seems supported to some extent by the fact that these saccades from and towards the fixation centre were relatively small and that their length distributions were almost similar for all test objects used, for target as well as for free eye movements.

As an illustration of these similarities, frequency polygons of the length distributions for one target size and one observer are given for the saccades from the fixation centre away (fig. 4.7*e*) and for the saccades back to this centre (fig. 4.7*f*). The averaged median value of the overall distributions amounted to 0.8° of visual angle for T.B. and 0.6° for F.E.

**4.5. Search time**

In contrast to the conspicuity-area experiments described in sec. 4.3, the observer was this time allowed to move his eyes during the stimulus pattern presentations which now lasted 4 s each. Only during the 1 s rest fields, which separated the subsequent stimulus patterns, he had to fixate the centre of the screen for calibration purpose. When he discovered the relevant test object he had to indicate this by means of the light signal. The stimulus patterns always contained two different test objects, one larger and the other smaller than the 0.55° background disks (fig. 4.1). In this way two different series of stimulus patterns were made available on video tape, see sec. 4.2.1. One series had a relatively conspicuous larger test object ($D$ = 0.69°) and an inconspicuous smaller one ($D$ = 0.45°) while the other series had an inconspicuous larger object ($D$ = 0.63°) and a relatively conspicuous smaller test object ($D$ = 0.34°). In four subsequent sessions the observers were instructed to search in turn for one of these four test objects, the target, and to avoid fixation on the other test object irrelevant to the present search task, the non-target. The discovery of the target was taken for granted when both the light signal appeared and the observer fixated the test object, the latter being an almost spontaneous reaction when he indeed discovered it.

4.5.1. *Results and discussion*

Figure 4.12 gives for both observers, the cumulative polygons of the number ($n$) of targets discovered against search time ($t$), i.e. the time elapsed between the stimulus onset and the moment of target fixation. The four experimental functions correspond to the four different targets used in the successive sessions.

With regard to the theoretical description of the experimental data in fig. 4.12, we shall now consider two somewhat extreme possibilities of the way our observers could have performed their search tasks. The first is the assumption of "systematic search", which is in a way comparable to sampling without replacement. It means that the observer avoids reexamination of areas already

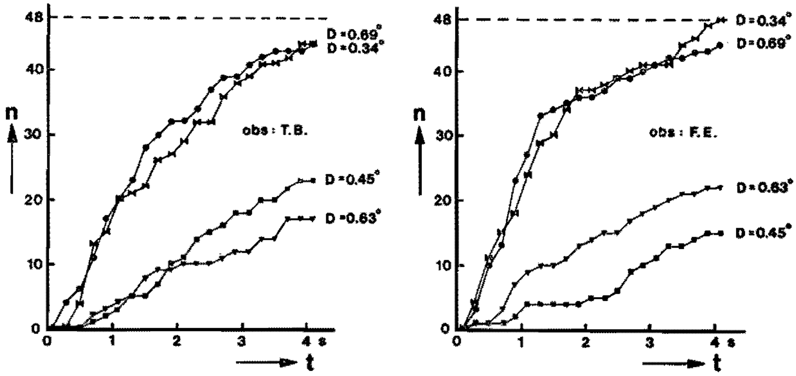


Fig. 4.12. For the observers T.B. and F.E. and the four different targets (with diameter $D$), the cumulative polygons of the number ($n$) of targets discovered against search time ($t$). The dotted line at $n = 48$ indicates the maximum number of targets, that could be discovered in a single series of stimulus patterns.

searched over. In an ideal search pattern of this type there is no overlap of the conspicuity areas, thought to be centred around the locations fixated. As a consequence the probability ($P_N$) of discovering the target at the $N$th fixation equals the single fixation probability ($P_1$) of target discovery, so the ratio of conspicuity area over display area; given as a formula:

$$P_N = P_1 \text{ for } 1 \leqslant N \leqslant 1/P_1. \tag{4.2}$$

Thus required search time will be finite here and the cumulative probability ($P_{cd}$) of target discovery will be described by a linear function of search time ($t$):

$$P_{cd}(t) = P_1 \cdot t/\bar{T}_{fix} \tag{4.3}$$

for

$$\bar{T}_{fix} \leqslant t \leqslant \bar{T}_{fix}/P_1.$$

In this formula $t/\bar{T}_{fix}$ corresponds to the number of fixations in $t$ seconds of search.

The second somewhat extreme possibility is the assumption of "non-systematic search", that is search by means of independent fixation positions over the display. Here the observer forgets as it were his previous fixation locations. In that case the probability of target discovery at the $N$th fixation decreases according to

$$P_N = P_1 (1 - P_1)^{N-1}. \tag{4.9}$$

The cumulative probability of discovering the target as a function of time then becomes

$$P_{cd}(t) = 1 - (1 - P_1)^{t/\bar{T}_{fix}} = 1 - e^{-at} \tag{4.5}$$

with

$$a = (-1/\bar{T}_{fix}) \ln (1 - P_1) \tag{4.6}$$

for

$$t \geqslant \bar{T}_{fix}.$$

The functions (4.3) and (4.5) ought to have the same initial slope, since for $t = \bar{T}_{fix}$, $P_{cd}$ equals $P_1$ in both cases.

For comparison fig. 4.13 gives the functions (4.3) and (4.5), fitted to one of the experimental curves of fig. 4.12.

Apparently our experimental data are approximated better by the assumption of non-systematic search, corresponding to a description by means of (4.5). This finding has been corroborated by results of others (Krendel and Wodinsky [4-14]), Bloomfield [4-15]). Also our further experimental cumulative distribution data were described reasonably well by exponential functions. The matching was done by applying linear regression calculations to the experimental data, which have been plotted for that purpose in fig. 4.14 on a semi-logarithmic scale in accordance with

$$1 - \frac{n}{48} = 1 - P_{cd} = e^{-at}. \tag{4.7}$$

Knowing the mean number of fixations per second ($1/\bar{T}_{fix}$) during search, $P_1$ values could be estimated by means of (4.6) and (4.7) from the slopes of these regression lines. (Estimating $P_1$ mathematically from the non-cumulative dis-

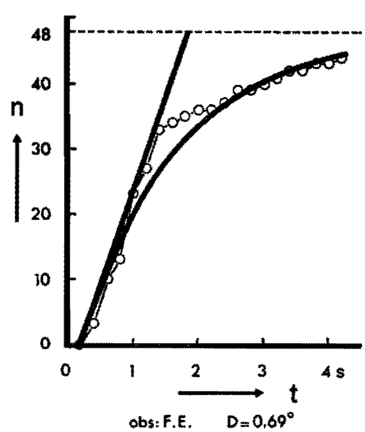


Fig. 4.13. One of the experimental functions given in fig. 4.12 (obs. F.E., $D = 0.69°$) approximated both, by a linear function of search time implying the assumption of systematic search, and by an exponential function of search time implying the assumption of non-systematic search.

tributions would be less convenient.) Since the successive target locations in a stimulus series were homogeneously distributed over the display area (fig. 4.2*b*), the effective size $\varrho$ of the conspicuity area during search, assumed to be circular, followed from

$$P_1 = \frac{\pi \varrho^2}{A} \tag{4.8}$$

In this formula $A$ stands for the area of the display.

In calculating the regression lines in fig. 4.14 we assumed $P_{cd} = 0$ for $0 \leqslant t \leqslant 0.2$ s, since the minimum time needed before discovery of the target and the accompanying saccade towards it, required at least some 200 ms; see fig. 4.7*c* in relation to this. The precise value chosen for this delay is, however,

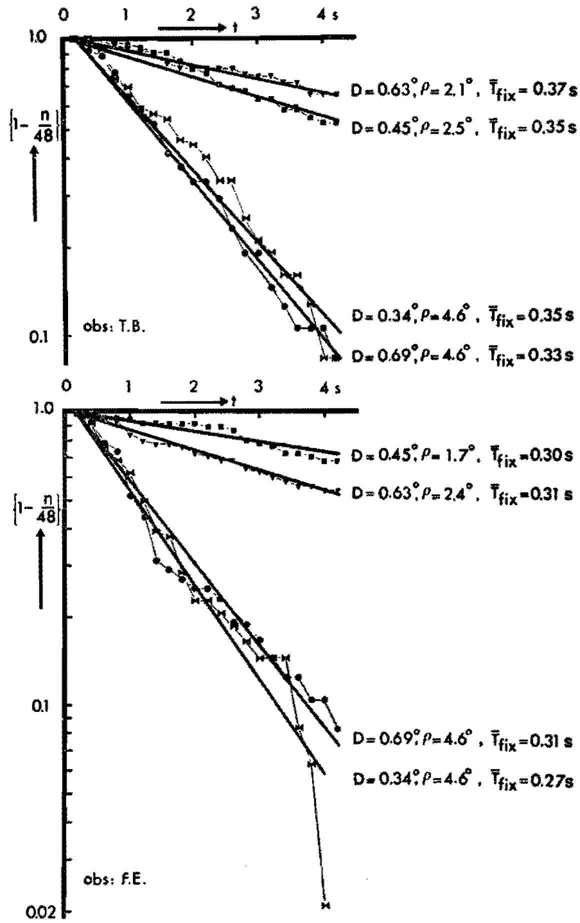


Fig. 4.14. The cumulative number ($n$) of target objects discovered as a function of time ($t$), plotted according to (4.7) on a semi-logarithmic scale. The effective size $\varrho$ of the conspicuity area during search can be derived via eqs (4.7), (4.6) and (4.8) from the slope of the relevant linear regression line.

not very critical with regard to the $P_l$ values derived from the experimental data.

Let us now compare the sizes $\bar{R}_{50}$ of the conspicuity areas as obtained by means of single-fixation exposures (sec. 4.3), with the effective sizes $\varrho$, determined by means of the cumulative probabilities of target discovery. As can be noted from fig. 4.15, the regression coefficient of $\varrho$ on $\bar{R}_{50}$ is smaller than 1, in fact the value calculated over the data of the two observers amounted to 0.67, the correlation coefficient being 0.93. A larger regression coefficient (0.8) can be obtained indeed by forcing the regression line through the origin.

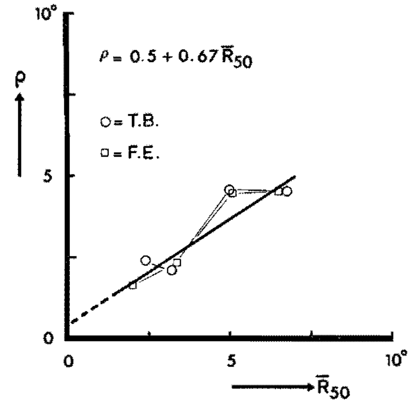


Fig. 4.15. The relationship between the sizes ($\bar{R}_{50}$) of the conspicuity areas, obtained through single fixation stimulus exposures and the effective sizes ($\varrho$) during search, determined from the cumulative probabilities of target discovery.

In formula (4.8) we assumed the conspicuity areas to be circular. However, in reality the conspicuity areas are non-circular in general. Therefore slightly larger values for the average eccentricity $\varrho$ of the area border will be obtained for the same area, but different in shape, if allowance is made for this fact. Further possible reasons for $\varrho$ found to be smaller than $\bar{R}_{50}$ will be mentioned in the general discussion (sec. 4.7.1).

Finally, $\bar{T}_{\mathrm{fix}}$ showed no significant correlation with $\bar{R}_{50}$, see fig. 4.14. The overall value of $\bar{T}_{\mathrm{fix}}$ amounted to 0.35 s for T.B. and to 0.29 s for F.E.

### 4.6. Spontaneous fixations

During search for the target, there appeared to be a tendency for fixation on the, to the search task irrelevant, non-target in the stimulus pattern. Figure 4.16 gives for both observers the cumulative number ($n$) of non-target fixations against their moment ($t$) of occurrence, as determined from the eye movement records.

By means of the procedure used in sec. 4.5, also here the cumulative data of the "spontaneous fixations" were converted into corresponding $\varrho$ values. Together with the cumulative fixation data of the four non-targets used, these values are given in fig. 4.17. The data are corrected here for the termination of search after target discovery.

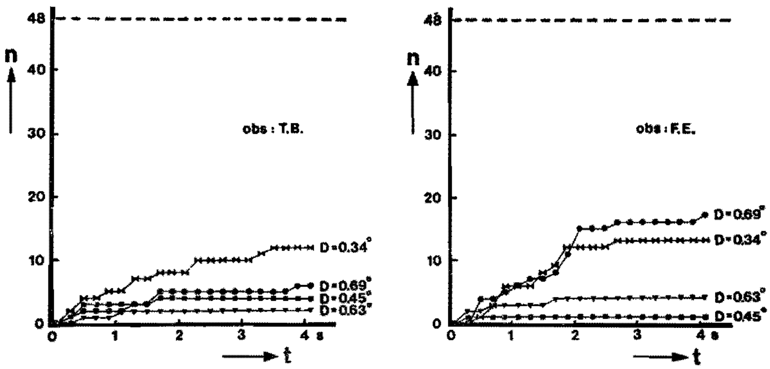


Fig. 4.16. The cumulative polygons of the number ($n$) of spontaneous non-target fixations during search for the target, for the observers T.B. and F.E., against their moment ($t$) of occurrence.

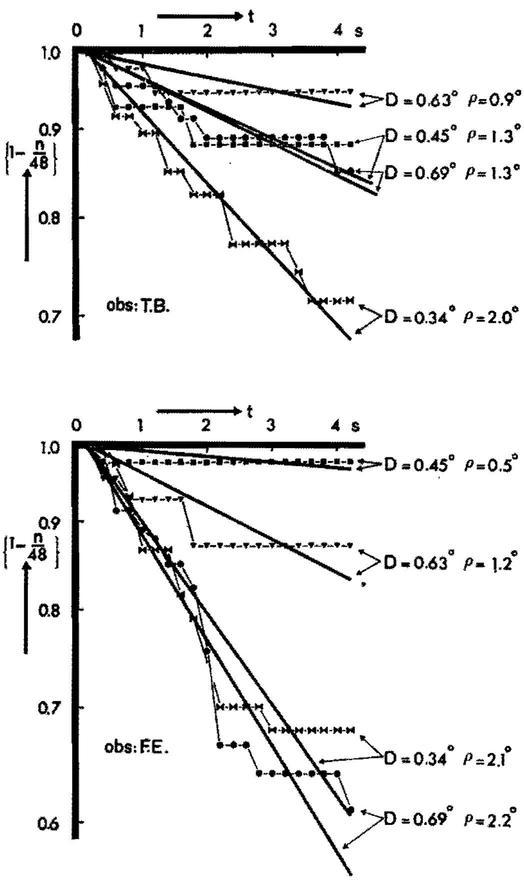


Fig. 4.17. The cumulative number ($n$) of fixations on the non-targets irrelevant to the search task as a function of time ($t$), plotted according to formula (4.7) as linear functions, together with the corresponding $\varrho$ values.

In view of the amount of non-linearity of our cornea-reflection method in supplying the locations of fixation over the display (at most about 1° of visual angle), we assumed that an object was fixated when the cornea-reflection spot appeared within 1° of visual angle from its centre after we corrected for drift with respect to the fixation on the centre of the previous rest field. Therefore, on the assumption of a random distribution of the fixation points over the display, $\varrho = 1°$ corresponds to test object fixation by accident.

From the results shown in fig. 4.18, underlined by other observer's similar results, it may be concluded that although it was the task of the observer to avoid fixation on the irrelevant non-target in the stimulus patterns they did not succeed too well. Most $\varrho$ values are namely larger than 1° of visual angle, which indicates that these non-targets were fixated more often than corresponds to a random distribution of fixation spots over the display.

Moreover, it is found from the $\varrho$ values given in fig. 4.18 that the probability of fixation on the non-targets is approximatively proportional to the squared size ($\bar{R}_{50}$) of the corresponding conspicuity area. ($\varrho \approx 0.3\ \bar{R}_{50}$). The overall correlation coefficient between $\varrho$ and $\bar{R}_{50}$ was 0.86 this time. In consequence the instruction not to fixate the non-targets instead of searching for them, resulted in a decrease of the regression coefficient of $\varrho$ on $\bar{R}_{50}$ by a factor of 0.28/0.67.

## 4.7. General discussion

From the experimental data presented two different relationships arose in the main. First there is the demonstrated connection between conspicuity area and the probability of target discovery against search time (secs 4.3 and 4.5) and second the relation between conspicuity and involuntary eye movements (secs 4.4 and 4.6). In the following sections we shall elaborate both points somewhat further.

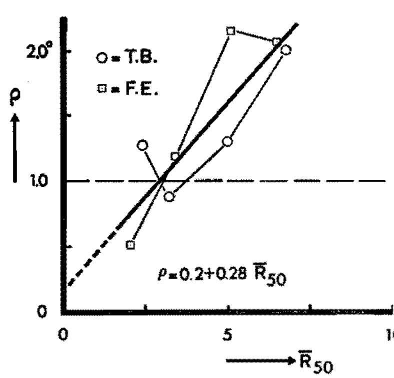


Fig. 4.18. The effective sizes $\varrho$ of the conspicuity areas for the non-targets, which are in proportion to their probability of fixation, against $\bar{R}_{50}$, the size of the corresponding conspicuity area. The dotted line indicates the $\varrho$ level that corresponds to test object fixation by accident.

4.7.1. *Conspicuity area and search time*

There is agreement in the literature concerning the possibility of describing the cumulative fraction of target discoveries against search time by an exponential function (Krendel and Wodinsky [4-14]), Bloomfield [4-15])). Accordingly formula (4.5) has also been suggested by these authors as applying to their data, implying the introduction of a hypothetical factor $P_1$ ,the single-fixation chance of discovery. Now, by means of the conspicuity-area concept and the experiments described, we succeeded in verifying the suggested formula experimentally, thereby relating the size of the conspicuity area to the probability of target discovery against search time.

However, for derivation of formula (4.5), the assumption of independent fixation position has been made, while it is known that the subsequent fixation positions during search are more or less related. Williams [4-16]) suggested therefore a somewhat subtler approach by assuming during search a repeated scanning of the display by dependent fixation positions. In relation to this it should be noted that it is probably only due to statistical deviation that the data in fig. 4.13 can also be approximated by two successive linear functions. This follows from inspection of fig. 4.14, where these results are presented together with the other experimental data. Actually all authors assume a random and consequently homogeneous distribution of fixation points over the display, which is not necessarily the case however (Brandt [4-17]), Enoch [4-18])). We have not checked on this requirement thoroughly in our results. A non-homogeneous distribution e.g. with a lower fixation density in the display corners would yield, however, a smaller asymptotic value for $P_{cd}$ and so a smaller effective size ($\varrho$) of the conspicuity area. This may then be a second reason, besides the minor one already given in sec. 4.5.1 on the influence of the assumption of a circular conspicuity area, for $\varrho$ to be about 70% of $\bar{R}_{50}$.

In relation to this deficiency it should also be noted that the conspicuity areas were determined by presenting the stimulus fields in between non-structured rest fields. This in contrast to the stimuli coming in during the successive fixations in regular search. Since it is known that structured stimuli succeeding each other in time may interfere with each other through backward and forward masking, it is not excluded that smaller conspicuity areas would be obtained if structured rest field were used.

In view of all these factors, that possibly improve the regression coefficient of $\varrho$ on $\bar{R}_{50}$, it is not of relevance to consider here the influence on this relation of the choice of the threshold level (50%, see fig. 4.5) used for determination of the sizes of the conspicuity areas.

From the nearly unchanged averaged durations of fixation ($\bar{T}_{fix}$) during search for the different targets, as given in fig. 4.14, it can be concluded that the observers did not adapt their fixation rate to the difficulty of the search task, at least not in a way that was statistically significant. A similar conclusion was obtained by Gordon [4–19]) for letter search through printed lists of varying complexity. The averaged fixation duration amounted to 0.35 s for T.B. and 0.29 s for F.E.

Since non-systematic search is comparable to sampling with replacement out of a bimodal set, an estimate of $P_1$ and consequently of $\varrho$ can also be obtained by determination of the ratio of the total number of times the relevant test object was discovered over the total number of fixations made. The values for $\varrho$ obtained in that way differed for targets at most 0.1° of visual angle from the values obtained via required search time (fig. 4.14), and at most 0.3° of visual angle from the $\varrho$ values obtained in that way for non-targets (fig. 4.17). This result is in line with the statement made above, that $\bar{T}_{\text{fix}}$ did not vary significantly with the difficulty of the search task.

It is interesting to note that Howarth and Bloomfield [4–20]) found the averaged search time ($\bar{t}$) to be inversely proportional to the squared difference in diameter between target disk and background disks. Our results corroborate their finding since it appears from the data given in fig. 4.6, that $\bar{R}_{50}$ is about proportional to the difference in diameter.

In relation to the exponential function of search time given by formula (4.5), it can be shown namely that the following applies for the averaged search time ($\bar{t}$):

$$\bar{t} = \int_0^\infty t\,P(t)\,\mathrm{d}t = \int_0^\infty t\,a\,\mathrm{e}^{-at}\,\mathrm{d}t = 1/a \tag{4.9}$$

Since

$$a = -\{\ln(1 - P_1)\}/\bar{T}_{\text{fix}} \tag{4.6}$$

$$\bar{t} = \frac{-\bar{T}_{\text{fix}}}{(-P_1 - P_1^2/2 - P_1^3/3\ldots.)}$$

and since $P_1 \ll 1$,

$$\bar{t} \approx \frac{\bar{T}_{\text{fix}}}{P_1}. \tag{4.10}$$

Since $P_1 \sim \pi\,(\bar{R}_{50})^2$ and $\bar{R}_{50} \sim |D - D_0|$ (fig. 4.6),

$$P_1 \sim (D - D_0)^2$$

so that

$$\bar{t} \sim \frac{1}{(D - D_0)^2}.$$

It should be noted, however, that for larger conspicuity areas the linear proportionality as given in fig. 4.6 probably does not apply (Engel [4–7])).

### 4.7.2. *Conspicuity area and spontaneous eye movements*

In secs 4.4 and 4.6 we have demonstrated the influence of visual conspicuity, on the occurrence of small spontaneous eye movements during obligatory fixation of the display centre and, on involuntary fixations during search, respectively.

In earlier work (Engel [4-1]) it was found to be clarifying to divide the factors controlling selective attention, into subject and object factors, or in the terms of Fechner [4-21]) into voluntary and involuntary determiners of attention. We then considered visual conspicuity to be an involuntary determiner of attention. Now that we are studying selection by way of eye movements, we shall distinguish in a similar way voluntary and involuntary determinants of eye movements. In fig. 4.19 we have tried to record our present ideas about these two subsequent selective actions in the visual system, in line with a flow diagram given earlier (Engel [4-1])).

At the first stage in fig. 4.19, there is a spatial selection by eye movements on the visual stimuli presented, the output being a signal flow limited by eccentric vision. Correspondingly, it is assumed that the representation of objects through activity in the corresponding information channels decreases with retinal eccentricity, the foveal signals being relatively emphasized. In figure 4.19 this has been indicated by the thickness of the arrows. In the following stage of feature extraction, conspicuity arises from mutual inhibitory interactions between units for identical features (Engel [4-7])). Irregularities in the stimulus pattern, such as, for instance our test objects deviating from the background, will then automatically yield a relatively increased activity of the corresponding

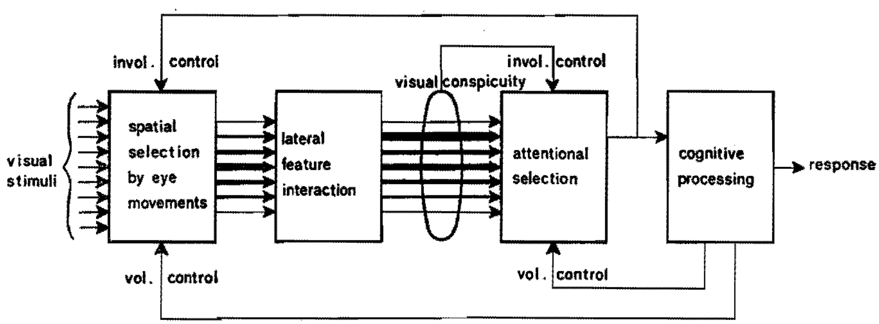


Fig. 4.19. A tentative diagram of selective data reduction in the visual system through eye movements and selective attention. Visual conspicuity, represented by relatively increased activity of certain information channels, caused particularly by lateral interferences among similar feature channels at the visibility stage, is considered to exercise involuntary control on selective attention and after that on eye movements. These involuntary controls are thought to be counteracted by voluntary controls. Two separate connections for voluntary control have been drawn from the stage of cognitive processing, since it was found from earlier experiments (Engel [4-1])) that selective attention could be uncoupled to a certain extent from the line of sight by voluntary act.

feature channels. This then will act upon selective attention, in line with proposals of Deutsch and Deutsch [4-22]) on the functioning of this mechanism, making the relevant information available for recognition and for a possible further response. The involuntary control signal for the eye movements, containing information about direction and eccentricity of the relevant object is thought to be drawn from the signals after selective attention. (The alternative possibility, tapping this signal off before selective attention, would require an additional selector for separation of the most conspicuous signal. For the moment a decisive answer on this point seems hard to give experimentally.) The involuntary controls are thought to be suppressible by voluntary controls. Our earlier attention area experiments (Engel [4-1])), in which the observer had to direct his attention towards a position eccentric from the obligatory fixation spot, indicated that selective attention could be uncoupled from the line of sight by voluntary control. It is for that reason, that we have drawn two separate connections from the last box in our diagram, which represents further cognitive processing, namely one for voluntary control of the eye movements and one for voluntary control of selective attention. The experimental results of Kaufman and Richards [4-23]) also agree with this distinction. They compared the points to which a naive observer believes his eyes are directed and those to which the eyes are oriented in fact.

Let us, in the light of fig. 4.19 now consider the spontaneous eye movements described in sec. 4.4. Their occurrence, as well as the delay time ($\Delta T_t$) before their occurrence, depended on the conspicuity of the target, namely on the size of the conspicuity area and on the eccentricity of presentation both (figs 4.8, 4.10 and 4.11). This result fits in with the assumptions made in relation to fig. 4.19, of a decreasing activity of the information channels with eccentricity and an activity increasing with conspicuity. Also the experimental results of Levy-Schoen [4-24, 25]), who observed that the nearest of two identical and simultaneously presented stimuli was generally fixated first, corroborate these assumptions. We then need to assume with respect to the delay times, that greater activation leads to shorter delay before directing of attention.

To understand the search time results (sec. 4.5) and the accompanying involuntary fixations on the non-targets (sec. 4.6), we assume that in the absence of critical features such as the test objects, irregularities in the background pattern, edges of the display etc., the eyes under global voluntary control show a quasi random search behaviour. This behaviour is characterized by saccades of a certain length and duration of fixation, both being mainly determined by display size (Enoch [4-18])) and perhaps by background complexity. This may account for the overall random fixation positions during search and the practically unchanged averaged fixation duration ($\bar{T}_{fix}$) with changing conspicuity of the target object. In reading, also, there is the suggestion of a rather autonomous motor programme for the eye saccades. Bouma and De Voogd [4-26]) concluded namely that only the average proceeding of the eyes over the text needs global control by text recognition.

When some critical feature calls upon attention, such as the non-target in our stimulus patterns, an eye movement will be initiated towards it. Only if the required additional decision: "target/non-target", to be taken by the cognitive stage, is performed fast enough, could the tendency of fixating the irrelevant test object be suppressed by voluntary control. In view of the results given in fig. 4.18 this occurred to a certain extent, resulting in a relatively decreased effective size ($\varrho$) of the conspicuity area for the non-target compared to the size obtained when this object was the target object. Since no extra visual input is involved here, the time interval between onset of the voluntary cancellation and the occurrence of the saccade must be larger than the roughly 100 ms refractory period preceding a saccade, in which observers are unable to react directly to a second target displacement (see e.g. Komoda et al. [4–27]), Levy-Schoen [4–24])).

In relation to this it is interesting to note that sometimes a substantial time gap was involved in our search experiments between the intake of target location and the moment of actual performance of the saccade towards the target. That is to say, it happened now and then that after a fixation by accident within the conspicuity area around the target, viz. after a large saccade, there first occurred a relatively large saccade away from the target, presumably under voluntary control, after which the eye returned in one or two jumps, the additional second jump back being a "corrective" saccade. The signal light then appeared afterwards with the usual delay. (For more information on these interesting smaller corrective saccades, which also occur in the absence of visual feedback, see e.g. Weber and Daroff [4–28])). Sometimes the effect also occurred after offset of the search pattern, making it acceptable that the observer used the information on target location, obtained just before cessation of the stimulus pattern during the first accidental fixation near the target object. This also points to the existence of some accurate internal representation of target location which remains available for a period of at least 2 or 3 saccades.

## 4.8. Conclusions

(1) By assuming a random distribution of fixation positions over the display area during search, we were able to relate experimentally the cumulative probability of target discovery against search time with the size of the conspicuity area concerned, the visual field in which the target can be discovered in a single fixation. As was derived from the search time data, the effective sizes of the conspicuity areas during search were found to be about 30% smaller than the conspicuity areas determined by means of single tachistoscopic presentations.

(2) During search, non-targets added to the stimulus pattern were found to be involuntarily fixated in proportion to their conspicuity area. In this case the

instruction not to fixate the non-targets resulted in a decrease, about 60%, of the effective size of the conspicuity area during search.

(3) During direct determination of the conspicuity areas, requiring strict fixation on the display centre, small to-and-fro eye movements of about 0.7° of visual angle in length occurred nevertheless in the direction of the target object discovered. Their occurrence as well as their delay with respect to stimulus onset depended on the size of the conspicuity area and on the eccentricity of presentation (figs 4.8, 4.10 and 4.11). These delays increased by about 200 ms over the transition region of the conspicuity area concerned. There existed a constant difference of about 300 ms between the occurrence of these eye movements and the manual recognition response of the observer.

(4) The obtained results were interpreted in terms of a tentative flow diagram of selective information reduction in the visual system (fig. 4.19). Visual conspicuity has been taken in relation to this to be an external determiner of both selective attention and eye movements.

(5) The experiments described emphatically demonstrate the usefulness of the conspicuity area as a concept for research on visual selection.

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# 5. FURTHER EVALUATION

The previous three chapters described the experimental findings concerning visual conspicuity as an external, involuntary determinant of eye movements and selective attention. In this concluding chapter an attempt is made to evaluate the main findings in somewhat greater depth. The experimental results obtained are first briefly reviewed in sec. 5.1. In the subsequent sections their implications are discussed more fully, especially in relation to recent findings and theories on human information processing in the literature. Some of the unsolved questions in this study, such as on the organisational principles that govern "Gestalt" perception in eccentric vision, are then examined. In this context the results of some additional experiments are also reported.

## 5.1. Experimental findings

In chapter 2 the size of the conspicuity area was introduced as a measure of visual conspicuity. The conspicuity area indicates the visual field around the observer's momentary eye fixation point, in which with unknown location the test object concerned may be noticed against its background. For the complex background patterns used, it was found that when the observer was asked to direct his attention (but not his eyes) towards a certain fixed eccentric location, without necessarily presenting the test object there, the result was an extension of the obtained area in that direction — a finding recently confirmed by Ikeda and Takeuchi [5-1]). The union of the areas thus obtained for different directions of selective attention coincided with the visibility area, i.e. the retinal field in which the presence of the test object can be discerned in its (complex) background, when its eccentric position is known. The visibility and the conspicuity areas thus turned out to be linked by directed attention.

Chapter 3 described experiments on the combined effect of different physical features of the test object on the size of the conspicuity area. This size was found to be determined by the contrast factor separately yielding the largest effect. With regard to combined contrasts in luminance, size and colour, therefore, no mutual enhancement was observed. A further assessment was also given of the observer's ability to perceive test objects with known location in eccentric vision. In this manner the visibility areas obtained for test disks in a structured background of randomly located background disks were found to be much smaller than the visibility areas for test disks on a plain non-structured background. The effect was too strong to be explained on the basis of regular visual acuity data. Moreover, a relative minimum was found in the size of the visibility area for a test disk identical with the background disks. From this finding it was inferred that the background disks exerted at least a size- and luminance-selective interference on the detectability of the test disk in eccentric vision. This type of "figure-ground detection" concerns merely the ability to perceive at a given eccentricity the presence of the relevant test object among the background objects in the stimulus pattern. This ability does not necessarily imply, however, that all the specific properties of the test object are actually perceived. For instance in this case of the smaller differences in diameter between the test and background disks in chapter 3, the presence of the test disk could be perceived at a given eccentricity through its luminance contrast where as the difference in diameter could not be discerned. For that reason in addition to the concept of visibility area the concept of discrimination area has been introduced, indicating the visual field in which the observer can perceive the difference between the test object and the background objects; when he knows the type of difference and the position of the former. The following sections will deal more extensively with the somewhat unexpected finding of feature-selective interaction, occurring already at the level of figure-ground detection.

Chapter 4 reported experimental results which related the conspicuity area to the probability of target discovery during a number of search tasks. It was demonstrated moreover that non-targets irrelevant to the search task in the stimulus pattern, were spontaneously fixated in proportion to their conspicuity area. The phenomenon that the observers could not easily prevent eye fixation on e.g. a smaller non-target disk, if the target was a larger disk, suggests that these spontaneous eye saccades are triggered at an earlier level of processing than that of target recognition. Finally chapter 4 described the small spontaneous eye movements that occurred during the determination of the conspicuity areas. This determination requires an exact fixation of the display centre during the presentation of the stimulus pattern. Nevertheless, some 200 ms after stimulus onset and about 300 ms before the manual recognition response, a small to-and-fro eye movement of about 0.7° visual angle frequently occurred in the direction of the discovered target.

The probability of occurrence and the latency of these movements depended on the size of the conspicuity area, as well as on the eccentricity of the target. The implications of these spontaneous eye movements will also be considered more extensively in the following sections.

### 5.2. Processing models

Stimulated by ideas from communication and computer technology, progress has been made since the early 1950's in structuring models of human information processing. In order to be able to evaluate our experimental findings in the light of the current theories in this field, certain established opinions will first be briefly described in this section. Since auditory research initially paved the way towards the shaping of contemporary thinking and models, and since these ideas are to a certain extent equivalent for vision, two of the most salient auditory contributions will be mentioned first. Some of the relevant visual findings will then be mentioned, resulting in an outline of the successive processing stages discernible within which our findings also fit.

The following example given by Deutsch and Deutsch [5-2]) roughly characterizes the sort of listening experiments used to investigate the limitations of selection and processing capacity in hearing: *We cannot listen effectively to the conversation of a friend on the telephone if someone else in the room is simultaneously giving us complex instructions as to what to say to him.*

An influential model accounting for the results of this type of research has been proposed by Broadbent [5-3]). The major characteristic of his model was the assumption of a tunable selective filter, which accepts the desired message from a temporary buffer store and rejects all others, followed by a limited capacity recognition stage. Supported by experimental evidence, Broadbent [5-3]) assumed this selection to be based on crude physical characteristics of the simultaneously presented auditory messages, such as differences in intensity, pitch and spatial direction.

Later, Treisman [5-4]) studied the role of verbal cues and meaning on her subjects' ability to shadow one out of two auditory messages in the absence of distinct physical differences between both signals. Since this task appeared to be possible to some extent, Treisman suggested that the incoming messages are analysed and selected successively by the nervous system, starting with a gradual selection on the basis of crude physical cues and proceeding to the identification of words and the selection of meaning. The important point in Treisman's model was the introduction of at least two distinct levels of selective attention, the first acting on detectable sensory features (the crude physical cues) mentioned above, the second selecting recognized items for meaning. In what follows we shall refer to the former attentional level as "sensory selection" and to the latter as "cognitive selection".

In visual research selective attention has been tackled mainly by studying the temporary storage functions that are assumed to accompany the mentioned stages of feature detection and item recognition. At the first stage of sensory feature analysis the incoming signals are assumed to be transformed into a sensory representation, which is maintained for a few tenths of a second in what is mainly denoted as "sensory memory". After sensory selection, the successively chosen items are recognized in "working memory", which is assumed to be part of the short-term memory system, containing various buffers, among them the visual buffer (Baddeley and Hitch [5-5])).

Experimental evidence in support of both a sensory memory and sensory selection in vision has come from the important work of Sperling [5-6]) and that of Averbach and Coriell [5-7]). They briefly displayed a complex letter array and indicated the location of the letter(s) to be reported up to about 300 ms later. They showed that more letters were potentially available than could be recalled without this partial report procedure. The relative improvement of reporting has been explained in terms of a changing order of transfer of items from sensory to short-term memory through switching of attentional (sensory) selection. Later Eriksen and Johnson [5-8] as well as Crowder and Morton [5-9] supplied evidence for the existence of a sensory memory in the auditory system as well.

By comparing the results of pre- and post-exposural instruction, indicating whether numbers or letters in the display had to be reported, Sperling [5-6] and Brown [5-10] found a slight improvement in response, indicating an influence of cognitive selection. A rather different type of evidence for the operation of cognitive selection in vision comes from ambiguous stimuli, such as homographs or visual figures like the Necker cube. With these stimuli it is not usually possible to be aware of both versions simultaneously. In fig. 5.1 an attempt is made to give a rough scheme of the successive stages of analysis and selection, discernable in vision and hearing.

The detection stage is characterized by the determination of the sensory features of the incoming signals, while in line with the ideas of Neisser [5-11] certain "preattentive, wholistic operations" are assumed to group similar sensory features into larger perceptual units (objects, words etc.), to which sensory selection may then be directed. In our case this stage is thought to be related to the visibility of objects in their background.

In the following stage different (primary) recognition units (also named "dictionary units" (Treisman [5-12]) or "logogens" (Morton [5-13])) are assumed to be activated to a certain extent by the selected perceptual unit, each corresponding to a different meaning. Assisted by secondary recognition, the contextually most likely interpretation is then chosen by cognitive selection. In our experiments this corresponds to the assignment of "target" or "non-target" to the already detected object, with a diameter deviating from the background objects.

Besides sensory- and cognitive-selection, two additional levels of selection are indicated in fig. 5.1. The first, which occurs at the entrance of the system, performs a selection on the available stimulus material by directing the visual and/or auditory receptors to the input of interest.

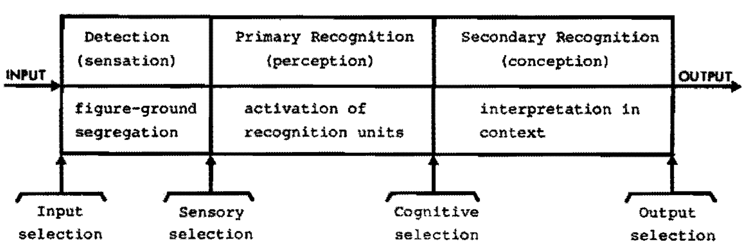


Fig. 5.1. Proposed outline of successive stages of analysis and selection in human information processing.

The second, present at the output, concerns the selection of the required response on the basis of the conceived stimulus interpretation. The possible outputs vary from overt responses like giving a voice output, a pushbutton action or even a change in input selection, to covert responses like storing the information in "long-term memory", assumed to be related to the stage of secondary recognition.

The distinction of four levels of selection comes closest to the four attentional strategies distinguished by Treisman [5–14]), which she indicated respectively by: selection of inputs, selection of analysers, selection of tests and targets and selection of outputs, as well as to the classification of selective attention given by Kahneman [5–15]). It should be noted that as a rule not all four selective stages are of clear relevance to the experimental tasks described in the literature. For that reason they are often not individually distinguished, thus giving confusions as to definition and interpretation of the selective stage actively involved.

The first two selective processes are frequently considered to be influenced by the "stimulus set": the subject's set enabling him to attend to stimuli with a specific sensory feature, while the last two selective stages are supposed to be affected by the "response set": the subject's set enabling him to attend to stimuli that have a certain meaning (see e.g. Broadbent [5–16])). It has been suggested by Broadbent [5–16]) and by Kahneman [5–15]) that the response set gives an increased amount of correct reactions combined with an increased amount of false reactions of the same type because of the lowering of the response threshold criterion. On the other hand the stimulus set should cause an increased number of correct reactions associated with a decreased number of false alarms on the same channel, i.e. an increased signal–to–noise ratio, because of the focussing of attention to a specific sensory channel. In terms of signal-detection theory (see e.g. Green and Swets [5–17])) the stimulus set should increase the sensitivity ($d'$) of the system, whereas the response set should lower the threshold criterion ($\beta$).

Now we may ask to which of these successive stages our experimental data given in chapters 2, 3 and 4 may be fitted. The selection of information by eye movements clearly corresponds to input selection. Further our experimental results on the influence of directed attention (chapter 2, figs 2.7 and 2.9), in the relevant direction characterised by an increased number of correct positive responses accompanied by a decreased amount of negative responses, may be ascribed to the stimulus set and thus presumably to voluntary control of sensory selection. Since sensory selection is assumed to act upon the sensory aspects of the stimuli presented, visual conspicuity may be considered to be the involuntary or external determinant of sensory selection. Indirect experimental evidence for the assumption that visual conspicuity also influences input selection is inferred from our eye movement data as described in chapter 4. There we found that during a search, non-targets were involuntarily fixated in proportion to the size of the corresponding conspicuity area. This result suggests that the spontaneous eye movements towards the non-targets were initiated through their conspicuity before the observers recognized it to be the non-target instead of the target, and as a consequence could prevent its fixation. Therefore visual conspicuity, as an external determinant of both eye movements and sensory selection, is in some way complementary to the stimulus set, the latter being the internal determinant of these two selectivities. The delay in recognition was also observed when the observers now and then continued searching for one or two saccades after target fixation, before they seemed to realize that they had discovered the target and as a consequence returned back to it. Luria and Strauss [5-18]) also observed this typical eye movement behaviour in their search experiments.

With regard to the determination of the conspicuity areas the observers were aware of the fact that the stimulus patterns contained only the target specified beforehand. Therefore noticing the target in eccentric vision only required the detection of something different from the background. It is possible, however, that naive observers based their responses on target recognition instead of target detection. For that reason it seems possible that the prolonged learning effects leading to an increase in conspicuity area were due to a gradual shift from target recognition towards detection as the criterion for a positive response.

If we assume that visual conspicuity influences sensory selection rather than cognitive selection, this attribute should arise out of the stimulus information already at the level of detection. This point will be considered more fully in the following section.

### 5.3. Object detection and selective interference

By means of our visibility area experiments we assessed the capability of our observers to detect at a known location in eccentric vision the presence of a given test object in a configuration of background objects. As mentioned earlier, this detection in a structured background does not necessarily imply that near the visibility threshold all differences in features relative to the background could be perceived. It only indicates the ability to discern the test object at a given eccentricity as a distinct entity among the other objects in the stimulus pattern. The results of the visibility area experiments (chapters 2 and 3) are therefore assumed to be related to the first stage of figure-ground detection and sensory memory in fig. 5.1.

The considerable difference in size between the visibility areas for the complex background configuration, and those for a plain background (chapter 3, figs 3.6 and 3.11) demonstrates the restricting influence exercised by the surrounding background objects. In our experimental situation this interference was shown to be at least size- and luminance-selective. Detection was hampered most if the test disk was identical in size and luminance to the background disks. In a comparable way Andriessen and Bouma [5-19]) supplied experimental evidence showing the existence of orientation-selective interference among straight line segments in eccentric vision, impairing the detection threshold of a test line amidst them. By way of illustration, fig. 5.2 shows the influence of size-selective and orientation-selective interference from neighbouring objects on the visibility of the relevant object in between.

Observable in fig. 5.2 and confirmed by observations reported by Townsend, Taylor and Brown [5-20]) the interferences are found to persist with prolonged viewing time, making it likely that they are mainly based on spatial rather than on temporal limitations of the visual system. When the group of three small circles in fig. 5.2. are observed in eccentric vision, the nearly complete disappearance of the central object may be perceived, suggesting that the interferences probably originate in the detection stage rather than in the following recognition stage.

A possible explanation for the selective interferences in our visibility area experiments is that the observers may have confused the test object with one of the surrounding objects owing to a gradual loss of information about the relevant retinal location over the 1 s interval that passed between the presentation of the location indicator and the actual display of the stimulus pattern. However, the experimental results of Slenders and De Swart [5-21]), who varied this interval, indicated that localization errors could be a minor cause only. Data on localization errors in eccentric vision also support this view (Attneave [5-22]), Leibowitz, Myers and Grant [5-23]), Harcum [5-24])). These errors, obtained for homogeneous backgrounds, were clearly smaller than the 8° of visual angle between the test disk and the nearest background disk in our experiments (chapter 3). Further Eriksen and Rohrbaugh [5-25]) showed that the confusion with neighbouring characters decreased when the time that the indicator preceded the display was shortened. Since localization errors seemed to be a minor cause only, we therefore suggested in chapter 3 that the interferences were the result of lateral adverse interactions among detector units for similar features, which decrease with increasing retinal distance.

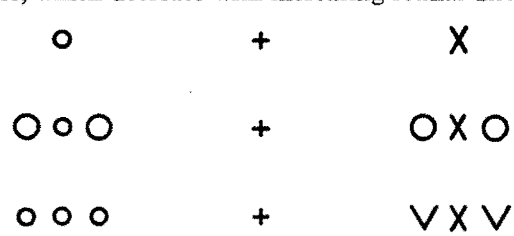


Fig. 5.2. Demonstration of size-selective interference (left) and orientation-selective interference (right) in eccentric vision. When the central crosses are successively fixated from the top downwards, the small circles in the left middle column and the crosses at the right are increasingly difficult to perceive, owing to specific interferences from the neighbouring objects.

Comparable interferences have been found in target letter detection experiments. McIntyre, Fox and Neale [5-26]) found detection accuracy to decrease with increasing physical similarity between target and noise letters, which can be accounted for in terms of an increased amount of activated feature detector units of the same type. Banks, Bodinger and Illige [5-27]) found this accuracy to decrease with spatial proximity between the letters, confirming the assumption of decreasing interaction with increasing retinal distance. Recently also Estes [5-28]) proposed "mutual interactions between feature detecting receptive fields" as an explanation for the adverse interactions among simultaneously presented characters.

Presumably these selective lateral interactions accentuate "irregularities" in the stimulus pattern, such as our test objects deviating from the background objects. Visual conspicuity, assumed to be related to this relatively increased activity of the corresponding detection units, may then act upon sensory selection and input selection through this increased activity, making the conspicuous information more available for subsequent recognition.

### 5.4. Similarity grouping and visual conspicuity

In this section we shall go somewhat further into the relations observed between visual conspicuity, "similarity grouping" and "subjective contours". Similarity grouping, the perceptual grouping into larger units of objects on the grounds of similarity and proximity, is a well known organisational principle in Gestalt Psychology (see e.g. Wertheimer [5-29])). In a number of experiments Beck [5-30, 31]) showed that the "peripheral discriminability under uncertainty" of objects in patterned visual fields (i.e. in our terminology their visual conspicuity) was inversely related to their effectiveness in producing similarity grouping. This relation can be explained on the assumption that similarity grouping is also based on the selective interactions described.

In relation to similarity grouping the perceptual segregation of adjacent fields of different uniform textures (the subjective contours) has been investigated by several authors (Julesz [5-32]), Beck [5-33]), Olson and Attneave [5-34]), Julesz, Gilbert and Shepp [5-35]), O'Callaghan [5-36])). In line with our assumption of feature-specific adverse interaction at the detection level, the subjective boundaries in these experiments appeared to be emphasized more effectively by differences in physical attributes, such as differences in density, luminance and local orientation of the texture elements, than by differences in cognitive attributes, such as the difference between two half arrays of 7-letter English words and 7-letter nonsense words respectively, both presented in upper case (Julesz [5-32])).

In order to gain further insight into the relation between similarity grouping and visual conspicuity, we compared in a pilot experiment the size of the binocular conspicuity area for a single test disk with that obtained for a cluster of three of these test disks in the same background configuration. The latter was realized by replacing two background disks adjacent to the first test disk by two disks identical to this test disk (fig. 5.3*a*). The size $(R_{50})_3$ of the conspicuity area for the cluster of three test disks was 6.0° visual angle, while the size $(R_{50})_1$ for the single test disk was 3.1° (fig. 5.3b), the mutual distance between three test disks being 1.2° of visual angle. From these values, and similar experimental data of a second observer, it followed that $(R_{50})_3$ was about 40% larger than the value expected from the union of the three constitutive conspicuity areas (fig. 5.3c).

On the grounds of the assumption of size-selective interferences, one would expect the visibility area and accordingly also the conspicuity area of the cluster of three test objects to be smaller than the union of the separate conspicuity areas. The finding of a larger conspicuity area seems to supply experimental evidence for the suggestion coming from Gestalt Psychology, that like parts tend to band together (Wertheimer [5-29])), yielding a new higher level perceptual unit with its own features relative to the background. The Gestalt school used the term "Prägnanz" for this tendency in perception towards completeness and relative simplicity of the percepts. However, the available knowledge of the grouping processes, occurring so evidently in eccentric vision, is clearly insufficient. In relation to the above described aspect of clustering, mention should also be made of the recent work of Uttal [5-37]). He proposed an autocorrelation model for describing the effect of the organizational properties of dotted visual forms on pattern detection in visual noise.

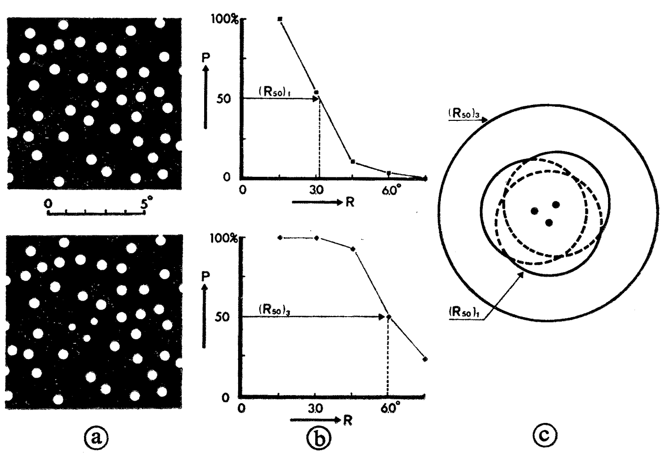


Fig. 5.3. The stimulus patterns used. At the top is the single test disk against the complex background; the cluster of three test disks in the same background configuration, is shown below. (*b*) For observer F.E. the percentage of correct test object discoveries (*P*) for both stimulus patterns as a function of the retinal eccentricity (*R*). (*c*) Comparison of the union of the three single-disk conspicuity areas with the actually obtained size of the conspicuity area.

## 5.5. Degree of visual prominence

Visual conspicuity was introduced in chapter 1 as the degree of perceptual prominence of a visible object against its background. Later we introduced the conspicuity area, and implicitly assumed that, if presented within this area, the relevant object would be able to control sensory selection. However, it is conceivable that the degree of perceptual prominence is not constant as a function of retinal eccentricity. In fact the conspicuity area determines only the region where this property is above threshold. Especially if two or more targets are presented simultaneously within their corresponding conspicuity areas, it would be of interest to acquire more knowledge about the "distribution of conspicuity" over the conspicuity areas. Which of the targets would then control the selection?

In some pilot experiments (Engel [5-38]) we simultaneously determined the conspicuity areas for two identical test disks, both presented at the same time against the random-disk background pattern. In the above situation, where both targets were presented simultaneously within their conspicuity areas, we found that both targets were also noticed. If this effect were to be explained in terms of the flow diagrams given in chapters 4 and 5, then selective attention would be capable of (successively) extracting the signals of the two targets from sensory memory; a task that can indeed be performed within the regular span of short-term memory (Sperling [3-39]). These experiments, therefore, gave us no decisive answer to the question of a possible difference in conspicuity as a function of retinal eccentricity.

In chapter 4 the small spontaneous eye movements were described that occurred in target direction during the presentations of the stimulus patterns while determining the conspicuity areas. The delay before the occurrence of these target eye movements increased with the eccentricity of target presentation. Because of the increasing delay, it is expected that if two identical targets are simultaneously presented, the nearer one will determine a possible target eye movement. Therefore such selective eye movements may give information on the distribution of conspicuity over the area. This was corroborated by Levy-Schoen [5-40]), who described some experiments in which two identical test dots were simultaneously presented at different eccentricities against a plain background. She reported that indeed the nearest of the two was fixated first.

## 5.6. Exploratory eye movements

By means of the search experiments described in chapter 4, we were able to demonstrate that, during the search for the target, previously specified non-targets in the stimulus patterns, on which the observer had to avoid fixation, were still fixated. The number of fixations was in proportion to the size of the non-target conspicuity area. This finding led us to suggest that visual conspicuity is an external determinant of input selection by eye movements also.

Since eye movements are also governed by internal determinants of cognitive origin, — one may decide where to fixate —, it follows that it is relevant to make the distinction of external and internal determinants at the level of input selection by eye movements as well. In line with this distinction with regard to the control of eye movements, Hochberg [5–41]) suggested a separation into "peripheral search guidance" and "cognitive search guidance", peripheral search guidance coming from the "low acuity information picked up in the periphery of the eye", and cognitive search guidance resulting from "knowledge about what has been seen so far".

Yarbus [5–42]) has studied patterns of fixation during the prolonged observation of natural pictures. A striking aspect of his records was the concentrations of fixation on certain areas of the display, such as on meaningful parts and on areas containing a relatively large amount of contours and brightness contrasts. Likewise Mackworth and Morandi [5–43]) reported that the informative areas in pictures attracted relatively more fixations. Somewhat later Jeannerod, Gerin and Pernier [5–44]) considered the order in which different parts of certain visual patterns were fixated. They remarked: *On est cependant frappé de la rigidité du trajet de l'axe du regard lorsque le temps d'exploration est prolongé et que celle-ci devient itérative.* Noton and Stark [5–45]) reported that similar "scanpaths" occurred intermittently but repeatedly during initial viewing and also during later recognition of the same picture. They therefore suggested that the visual patterns are represented in the memory as a sequence of sensory features, corresponding to the eye movements made. However, since the scanpaths for the same visual pattern to be remembered, were unequal for different observers, Noton and Stark [5–45]) rejected an explanation of the scanpaths in terms of "low-level control of the eye by peripheral feature detectors". Since most of their pictures were meaningful patterns, this implies that the scanpaths they found were probably related to cognitive aspects of their pictures, or perhaps to a more personal fixation routine of their subjects. By introducing a more operational definition, Locher and Nodine [5–46]) verified the scanpath phenomenon. They found experimental evidence for the occurrence of a scanpath in the recognition phase, similar to that in the learning phase of the same visual pattern, thus supporting the results of Noton and Stark [5–45]). However, they did not found that the occurrence of a similar scanpath in the recognition phase of the experiment also implied correct remembering of the visual pattern concerned. They seemed, therefore, to disprove the memory trace explanation. Since Locher and Nodine [5–46]) used meaningless, random geometric shapes in their experiments, it is likely that in the absence of important cognitive aspects in their stimuli, the sensory cues would dominate the scanpaths found. They did not report, however, on the possible resemblance of scanpaths for the same figures for different observers.

Clearly an appraisal of the relative influence of cognitive and sensory cues on the control of eye movements awaits further investigations, especially if we remember that these cues need not be of visual origin only. For instance in daily life, the warbling of a bird may also guide the movements of our eyes.

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**Summary**

Selectivity is a characteristic aspect of visual perception. At any moment only a small part of our environment can be clearly perceived. In doing so, certain things usually appear to attract attention and to catch the eyes in a given situation, whereas other ones remain unobserved. In the present thesis a number of experiments are described aimed at increasing the systematic knowledge of selective information processing in vision (chapter 1). With regard to the factors governing selection, a distinction is made between internal and external influences, also referred to as subject and object factors, respectively.

Chapter 2 deals with the essence of this investigation, namely the concept of visual conspicuity, which is defined as the object factor or, more precisely, as the set of object factors (physical properties), determining the probability that a visible object will be noticed against its background. It should be noted that visibility does not imply visual conspicuity. For example, a certain object may be visible among identical objects without being conspicuous. Furthermore, visual conspicuity is to be distinguished from cognitive conspicuity, for instance due to an incompatibility in the meaning of the stimulus.

As an experimental measure of visual conspicuity, the size of the so-called conspicuity area has been introduced in chapter 2. The conspicuity area indicates the visual field around the instantaneous fixation spot in which the relevant object can be noticed during a brief presentation (about 0.1 s) of this object against its background, without the subject having foreknowledge of its (retinal) position. A large conspicuity area then corresponds to a great conspicuousness of the object against its background.

The field in which the observer who has foreknowledge of the possible position of the object may detect it presence in the surroundings, is called the visibility area. In general these areas are indeed found to be larger than their associated conspicuity areas.

In chapter 2 it is made plausible by means of experiments that these differences between the visibility and conspicuity area result from directed attention (governed by expectation) towards the relevant eccentric position.

In chapter 3 a study is undertaken of the effect of some physical factors on the size of the conspicuity area. To this end use is made of circular test specimens variable in diameter and luminance in a background of randomly located disks. The experimental data reveal that the size of the conspicuity area is governed by the most dominant factor only. Hence combining several factors does not have a favourable effect on the size of the conspicuity area.

Chapter 3 also deals with the influence of the applied background disk pattern on the size of the visibility area of the test disk. These areas are found to be much smaller than could be expected from the available visual acuity data on eccentric vision. Moreover, a relative minimum was found in the size of the visibility area for a test disk identical to the background disks. This result is

explained in terms of inhibitory interactions between retinally neighbouring detector units for similar features. Conversely features deviating from the background properties may then automatically attract the subject's attention through their less inhibited representation. This means that visual conspicuity, i.e. the relative accentuation of deviating properties, would arise already at a level of feature detection.

Chapter 4 treats the influence of visual conspicuity on selective eye-movement behaviour. The stimulus patterns therefore contained in addition to randomly located uniform background disks a smaller and a larger test disk, both being randomly located as well. The observer was asked to look for the previously specified (for instance larger) test disk indicated by "target" and, in doing so, to prevent fixation of the other "non-target" test disk. The results revealed that the probability of finding the target as a function of the search time is indeed related to the size of the relevant conspicuity area. However, the number of fixations on the non-target, while searching for the target, was also found to depend on the size of the corresponding conspicuity area. As a consequence, visual conspicuity may be considered as an external determinant of both selective attention and eye movements. In the model of the selective processing of information in the visual system presented in chapter 4, it is assumed that the visual conspicuity influences the eye movements through selective attention.

The fact that the observer only partially succeeded in avoiding non-target fixation while searching for the target might imply that the eye movements in question were initiated at an earlier processing level than at the level where the test disk deviating from the background is recognized as a non-target. This would confirm the earlier suggestion that visual conspicuity indeed arises at the level of feature detection. The observation that observers now and then continued to search for one or two fixations after fixating the target also points to the lagging of recognition.

In the direct determination of the conspicuity area, the observer was asked to fixate the display centre strictly during the brief presentation of the stimulus pattern. From a close observation of the above eye fixations we found that some 200 ms after stimulus onset there occurred a small eye movement (about 0.7° visual angle long), especially if the test object was discovered. These small spontaneous eye movements are analysed further in chapter 4. From the results of this analysis we found that instant of onset of these movements is dependent on the conspicuity of the test object, i.e. on the size of the relevant conspicuity area and on the retinal eccentricity of the test object. The conspicuity area only indicates the boundary of the visual field in which the object becomes prominent. Perhaps something can be said about the distribution of the conspicuousness within the conspicuity area, if these spontaneous eye movements were to be investigated in relation to the simultaneous presentation of two test objects at different eccentricities.

Finally, an attempt is made in chapter 5 to fit the experimental findings and their interpretation into the current knowledge about human information processing. For that reason a crude model of various distinguishable processes has been derived from the literature in which the experimental findings described in this thesis can be included.

**Samenvatting**

Kenmerkend voor de visuele waarneming is haar selectieve karakter. Van al wat ons omringt kan op ieder moment steeds slechts een beperkt deel duidelijk waargenomen worden. In een gegeven situatie blijken daarbij veelal bepaalde delen algemeen de aandacht te trekken en de blik te vangen, terwijl andere onopgemerkt blijven. In dit proefschrift zijn een aantal experimenten beschreven, waarmee getracht is tot meer kennis te komen over de systematiek die aan deze selectieve verwerking ten grondslag ligt.

Daartoe worden in hoofdstuk 1 de betreffende selectieve processen (selectie door aandacht en door oogbewegingen) kort ingeleid. Ten aanzien van de selectie-bepalende factoren wordt daarbij een onderscheid gemaakt tussen oorzaken van interne en van externe oorsprong, ook wel aangeduid met respectievelijk subject en object factoren.

In hoofdstuk 2 wordt verder ingegaan op de spil van het onderzoek, het begrip visuele opvallendheid. Visuele opvallendheid wordt daarbij gedefinieerd als de object factor, of beter gezegd als de verzameling van object factoren (fysische eigenschappen), die bepalend zijn voor de mate van waarschijnlijkheid dat een zichtbaar voorwerp in zijn achtergrond opgemerkt wordt. Hierbij dient vermeld te worden dat zichtbaarheid nog geen opvallendheid impliceert; een bepaald voorwerp kan bijvoorbeeld tussen soortgelijke voorwerpen zichtbaar zijn, maar hoeft daardoor nog niet opvallend te zijn.

Voorts dient visuele opvallendheid onderscheiden te worden van „cognitieve" opvallendheid, d.w.z. van opvallendheid door betekenis.

Als experimentele maat voor visuele opvallendheid wordt in hoofdstuk 2 de grootte van het zogenoemde opvallendheidsgebied geïntroduceerd. Het opvallendheidsgebied geeft het gezichtsveld rond het momentane blikpunt aan, waarbinnen het betreffende voorwerp in zijn achtergrond opgemerkt kan worden tijdens een kortdurende (ongeveer 0.1 s) presentatie van voorwerp en achtergrond, zonder voorkennis van de plaats (retinale positie) van het bedoelde voorwerp in het gezichtsveld. Een groot opvallendheidsgebied komt daarbij overeen met een grote opvallendheid van het voorwerp in zijn achtergrond.

Het gebied waarbinnen de waarnemer de aanwezigheid van het betreffende object in zijn achtergrond kan detecteren, met voorkennis van de retinale positie in het blikveld, wordt het zichtbaarheidsgebied genoemd. Voor de in de experimenten gebruikte complexe achtergrondspatronen blijkt dat de zichtbaarheidsgebieden doorgaans groter zijn dan de bijbehorende opvallendheidsgebieden. In hoofdstuk 2 wordt experimenteel aannemelijk gemaakt dat deze verschillen tussen zichtbaarheids- en opvallendheidsgebied begrepen kunnen worden uit de invloed van het bewust richten van de aandacht (door middel van verwachting als subject factor) naar de betreffende excentrische positie.

In hoofdstuk 3 worden de invloeden nader bestudeerd van enkele fysische factoren op de grootte van het opvallendheidsgebied. Daartoe is gebruik ge-

maakt van een in diameter en luminantie variabele testschijf in een achtergrond van willekeurig geplaatste, onderling gelijke, achtergrondsschijven. Uit de experimentele resultaten blijkt dat het opvallendheidsgebied nagenoeg volledig bepaald wordt door de meest dominante factor van de twee. Het combineren van meerdere factoren levert dus ten aanzien van de grootte van het opvallendheidsgebied geen voordeel op.

Voorts wordt in hoofdstuk 3 dieper ingegaan op de invloed van het gebruikte achtergronds (schijven) patroon op de grootte van het zichtbaarheidsgebied van de testschijf. Deze zichtbaarheidsgebieden blijken namelijk veel kleiner te zijn dan op basis van normale gezichtsscherpte gegevens voor het excentrische zien verwacht mag worden.

Bovendien blijkt er een relatief minimum in de grootte van de zichtbaarheidsgebieden gevonden te worden voor een testschijf identiek aan de achtergrondsschijven. Als verklaring wordt geopperd dat dit resultaat het gevolg zou kunnen zijn van de aanwezigheid van inhibitieve interacties tussen gelijksoortige, retinaal naburige, kenmerk-detectoren. Omgekeerd zouden van de achtergrond afwijkende eigenschappen zodoende door hun minder verzwakte representatie (intensiteit) automatisch de aandacht tot zich kunnen trekken; hetgeen betekent dat visuele opvallendheid, de relatieve accentuering van afwijkende eigenschappen, reeds op kenmerk-detectie-niveau zou ontstaan.

In hoofdstuk 4 wordt de invloed van visuele opvallendheid op het selectieve oogbewegingsgedrag nader onderzocht. Daartoe bevatten de gebruikte stimuluspatronen behalve de willekeurig geplaatste, onderling gelijke, achtergrondsschijven steeds een kleinere en een grotere testschijf; beide eveneens willekeurig geplaatst. Aan de waarnemer werd daarbij gevraagd om de tevoren als „doel" aangegeven (bijv. grotere) testschijf te zoeken en daarbij de andere met „niet-doel" aangeduide (kleinere) testschijf niet te fixeren. Uit de resultaten blijkt dat de waarschijnlijkheid van het vinden van het doel, als functie van de zoektijd, inderdaad samenhangt met de grootte van het betreffende opvallendheidsgebied. Echter ook de mate waarin de niet-doelen, tijdens het zoeken van de doelen, spontaan toch gefixeerd werden, bleek samen te hangen met de grootte van het bijbehorende opvallendheidsgebied. Visuele opvallendheid kan dus, behalve als externe bepaler van selectieve aandacht, tevens opgevat worden als externe determinant van oogbewegingen. In de in hoofdstuk 4 gepresenteerde modelmatige voorstelling van de selectieve verwerking van informatie in het visuele systeem, is verondersteld dat visuele opvallendheid de oogbewegingen via de selectieve aandacht beïnvloedt.

Het feit dat de waarnemers er maar ten dele in slaagden om, tijdens het zoeken van het doel, het niet-doel niet te fixeren, zou er op kunnen duiden, dat de betreffende oogbewegingen op een eerder verwerkingsniveau geïnitieerd werden dan dat waarop de van de achtergrond afwijkende testschijf als niet-doel herkend wordt. Dit zou dan de eerder genoemde veronderstelling bevestigen, dat visuele opvallendheid inderdaad op het niveau van kenmerk-detectie ontstaat. Ook de observatie dat de waarnemers nog al eens, na het doel gefixeerd te hebben, gedurende 1 à 2 fixaties doorgingen met het zoeken, duidt op het later komen van de herkenning.

Bij de directe bepaling van de opvallendheidsgebieden wordt de waarnemer gevraagd om, tijdens de kortdurende aanbiedingen van het stimuluspatroon, het display-midden strak te blijven fixeren. Uit nauwkeurige observatie van deze oogfixaties is gebleken dat nog al eens, ongeveer 200 ms na het begin van de aanbieding, een kleine oogbeweging (ongeveer 0,7° gezichtshoek in lengte) voorkwam, speciaal wanneer het testobject ontdekt werd. Deze kleine spontane oogbewegingen zijn in hoofdstuk 4 verder geanalyseerd. Uit de resultaten van deze analyse blijkt onder meer dat het moment van inzet van deze bewegingen afhankelijk is van de opvallendheid van het testobject, d.w.z. van de grootte van het betreffende opvallendheidsgebied en van de retinale excentriciteit waarop het testobject wordt aangeboden. Het opvallendheidsgebied geeft slechts de grens van het gezichtsveld aan, waarbinnen het betreffende voorwerp in zijn achtergrond opvalt. Het is niet uitgesloten dat door het simultaan aanbieden van 2 testobjecten, door middel van deze reflexmatig aandoende oogbewegingen een uitspraak gedaan kan worden over het verloop van de opvallendheid binnen het opvallendheidsgebied.

Tenslotte is in hoofdstuk 5 een poging ondernomen om de gevonden experimentele resultaten en hun interpretatie in te passen in wat er heden ten dage bekend is over de informatieverwerkende processen bij de mens. Onder meer is daartoe uit de literatuur een globaal model van de successief onderscheidbare processen geabstraheerd, waarbinnen de in dit proefschrift beschreven experimentele resultaten inpasbaar blijken te zijn.

**Nawoord**

Het hier beschreven onderzoek is mogelijk geworden dankzij het vruchtbare werkklimaat op het Instituut voor Perceptie Onderzoek. Ik waardeer het daarom in hoge mate dat Prof. Dr. J. F. Schouten, de vroegere directeur en oprichter van dit instituut, bij dit proefschrift eerste promotor is.

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**Curriculum vitae**

De schrijver werd in 1935 te Amsterdam geboren. In 1947 beëindigde hij met succes de lagere school, en bouwde hij zijn eerste kristalontvanger. In 1952 begon hij met het inmiddels verworven diploma 3j. H.B.S.-b de opleiding Electrotechniek aan de H.T.S.-Amsterdam. Zijn belangstelling voor de zintuiglijke waarneming werd gewekt tijdens H.T.S.-stages bij het Acoustisch Laboratorium van de Piëzo-Electrische Industrie "Ronette" te Amsterdam en bij de Keel- Neus- Oor-Kliniek van het Wilhelmina Gasthuis te Amsterdam. In 1956 werd het H.T.S.-diploma behaald. Na beëindiging van de militaire dienst in 1958, werd aan de T.H.-Eindhoven de studie Electrotechniek begonnen. De belangstelling voor de menselijke waarneming werd tijdens deze studie krachtig gestimuleerd door een stage op het Instituut voor Perceptie Onderzoek onder leiding van Dr. R. J. Ritsma *). Afgestudeerd werd bij de groep Digitale Systemen, onder leiding van Prof. Ir. A. Heetman. Vanaf 1964 is de schrijver als wetenschappelijk onderzoeker in dienst bij het Natuurkundig Laboratorium van de N.V. Philips' Gloeilampenfabrieken te Eindhoven, waarbij hij van 1967 tot 1975 werkzaam was bij de Visuele Groep van het Instituut voor Perceptie Onderzoek.

*) R. J. Ritsma and F. L. Engel, Pitch of frequency modulated signals, J. Acoust. Soc. Am. **36**, 1637-1644, 1964.

STELLINGEN

bij het proefschrift van

F. L. Engel

14 december 1976
T.H. Eindhoven

I

Door het ontbreken van voldoende hulp en begeleiding bij de verdere uitwerking, fabricage en distributie, groeien bruikbare ontwerpen en ideeën op het gebied van technische hulpmiddelen voor gehandicapten doorgaans niet uit tot algemeen verkrijgbare producten.

H. Bouma, F. L. Engel and H. E. M. Mélotte, Technological devices for the visually handicapped: Gap between research effort and available aids, I.P.O. Annual Progress Report, 7, 46-54, 1972.

II

Bestudering van waarnemingsdrempels in het excentrische zien, biedt de mogelijkheid tot het verkrijgen van meer inzicht in het globaal zien.

Dit proefschrift.

III

Visuele oriëntatie-reacties, zoals de spontane oogbewegingen beschreven in hoofdstuk 4 van dit proefschrift, kunnen mogelijk een aanduiding zijn voor de mate van auditieve opvallendheid van een geluidsignaal in de omgeving van de betreffende waarnemer.

IV

De visuele opvallendheid van het oranje verkeerslicht is veelal gering nabij kruispunten verlicht met natrium-verlichting.

V

Doordat remlicht en achterlicht vaak in één armatuur gecombineerd zijn, resulteert het (overigens aan te bevelen) rijden met groot licht tijdens slecht weer overdag, in een geringe herkenbaarheid van de remlichten.

VI

Het boeiende van perceptie-onderzoek is dat, door het handig kiezen van het stimulusmateriaal, op basis van non-destructief onderzoek toch conclusies getrokken kunnen worden over de werking van de zintuigen.

R. J. Ritsma and F. L. Engel, Pitch of frequency modulated signals, J. Acoust. Soc. Am. **36**, 1637-1644, 1964.

VII

Het tegen de wil van de schrijver mogelijk toch nog aanwezig zijn van zetfouten in dit proefschrift, duidt op een interessant perceptief probleem.

VIII

Voor een loket met glasbeveiliging is, functioneel gezien, practisch ieder mens auditief gehandicapt.