THE SELECTIVE PROCESS IN THE FUNCTIONAL VISUAL FIELD

A. F. SANDERS

INSTITUTE FOR PERCEPTION RVO-TNO

NATIONAL DEFENCE RESEARCH ORGANIZATION TNO

SOESTERBERG - THE NETHERLANDS

1963

Gedrukt ter Koninklijke Drukkerij Van Gorcum & Comp.

PREFACE

In the history of science it often happens that the urgent need for practical know-how substantially stimulates further basic exploration of the field concerned. This is very much true for the study of human behavior with respect to new features in the tasks, given to the human operator in many contemporary machineries. In the revolution as in progress by large-scale introduction of automation, the development engineer, who is responsible for the hardware, recognizes that human capabilities and human failures have a decisive influence on efficiency and safety of his costly equipments.

Essentially these well-worn facts stand at the base of the study as reported in the underlying monography from the hand of Dr. Sanders. The author graduated in psychology at Leyden University and then, in 1956, entered as a staff member the Institute for Perception R.V.O.-T.N.O. at Soesterberg. The institute is engaged with the scientific study – applied as well as basic – of the perceptual capabilities and its connection with human behavior.

He then met there no colleagues of his own profession, but only physicists, engineers and specialized medical-physiological people. All these recognized – although it was not for all of them a fast process – that the newcomer indeed mastered a good number of useful scientific tools which had very urgently to be shared with their own in behalf of the common goal, but who seemed to speak a different language. Some time had to pass before in good harmony mutual cooperation, stimulation and appreciation between the different disciplined scientists had grown. Without the support given by so much distinguished colleagues, especially in the anglosaxon countries – I here especially mention the hospitality given by the Applied Psychology Research Unit of Dr. Broadbent in Cambridge, U.K. where Dr. Sanders spend half a year in 1957-1958 – it would have taken more time.

In the report the author's work on aspects of the functional visual field is brought together. The position is taken by him that a promising new general approach to the phenomena of set and attention is only possible by a more detailed knowledge about the selective process at the perception and at the assimilation of information. Single channel transmission and discontinuous course of the selective process are emphasized. Step by step the author anatomized, by different conditions of presentation of visual stimuli, the general principles of perceptual selective strategies. The conditions under which grouping of signals in one single selective act or the successive handling of stimuli occurs are studied in great detail. On the results a theory about the selective process in the visual field is built in which distinction is made between selective processes where both head and eye movements are needed and where eye movements only or even steady eye and head are sufficient to transmit the relevant information. Some implications for evaluation of the perceptual load in practical tasks – it was this problem that did initiate the study – show perspectives for future research in this field. The author clearly stated that for a more general theory on set and attention there is still a lot to be done. Let us hope that the synthesis, he has given of his own ideas, might be also extended by his own further contributions.

MAARTEN A. BOUMAN

CONTENTS

CHAPTER I

ON THE PRINCIPLE OF SELECTION

A. GENERAL CONSIDERATIONS

1. Introduction

The selective principle refers to the choice aspects of behaviour. The organism, being continuously faced with a mass of stimulation, can only assimilate a limited amount at a given instant and therefore a choice is necessary. So only a few stimuli of the total mass are actually processed; they affect directly the course of behaviour while the remainder serves as a background.

From a common sense viewpoint there are several kinds of selective activity. Selection can be "voluntary" or "involuntary", a discrimination indicating wether the selection of the stimuli is more due to the organism or to the stimuli itself. The term "attention" has been frequently used in this context. Selective activity is also present however, in cases where no attention seems to be required as in automatised actions and in completely familiar situations. Further, selective phenomena take place in a large variety of behavioral situations. There is perceptual choice in various sense areas, there is choice between solution strategies in problem solving and there is choice at affective decisions. Thus, selectivity is manyfold and according to common sense opinion it is an essential condition to behaviour.

This has been clearly expressed by James (1890) in the classical statement that "without selective interest, experience is an utter chaos".

Also from the objective and more experimentally minded side, there has been a general consensus of opinion about the existence of selectivity. As Gibson (1941) says, "the facts make it absolutely unavoidable", and indeed from the early observations on "prior entry" until the recent research on dichotic listening and multisource tasks, evidence has been brought forward that selection – and consequently rejection – of stimulation takes place. Nevertheless, the selective principle has not received an important position in most modern theoretical formulations on behaviour. Hebb (1949) argues that "psychologists have generally recognized the existence of attention or the like ... but they have done so reluctantly and sparingly, and have never recognized the fact in setting up theories".

As a reason for this situation, Hebb (op. cit) remarks: "the reluctance is partly no doubt because of a feeling that the concept is animistic, in some obscure way". This animism refers to the general anxiety of psychologists about the homunculus idea. Selectivity implies some inner control of behaviour, which is independent of afferent stimuli. From here to an inner agent sorting out those parts of stimulation that can be used – the homunculus – is only a small step. According to Attneave (1961), the rejection of the homunculus idea has two major bases: "The first is a morbid fear of ghosts, that is a fear of admitting into ones thinking anything that might possibly be suspected of immateriality. The second objection ... has to do with the supposedly regressive nature of the concept: If all the responsibility for perception and actions is attributed to a homunculus, explaining his behavior poses exactly the same problem as explaining that of the whole organism and we have got nowhere".

Attneave argues, that neither objection is decisive since, "we may suppose that, if a homunculus exists, it must certainly be composed of neurons. In the second place it should be noted that we fall into a regress only if we try to make the homunculus do everything.

The moment we specify certain processes that occur outside the homunculus, we are merely classifying or partitioning psychological functions".

What is called "homunculus" in the Attneave paper is called the "central autonomous process" by Hebb and it has received a large number of other names throughout the history of experimental psychology. They all point to the principle of selection or to the fact that "responses are determined by something else besides the immediately preceding sensory stimulation" (Hebb, op. cit.). In itself this fact neither gives a decisive answer to the mind - body problem nor to the determinism - indeterminism controversy. It recognizes only that the organism disposes of a directing function. How this function is interpreted is another question: It might be entirely composed of drives and learned schemata or habits, which work as a kind of filter the incoming stimulation has to pass before further central processing is possible. It might also be defended that the directive function is partly governed by free will. This is a philosophical problem, which has to be avoided as much as possible in the construction of psychological models.

A second reason for the reluctant attitude towards selectivity is that it is not easy to come to grips with the concept in empirical terms. This is the main objection, put foward by Gibson (1941). Selectivity is indicated by many terms as "set (in various connotations as neural set, organic set and the like), expectation, hypothesis, anticipation, foresight, intention, attitude, directing or determining tendency, tension, vector, need, attention, perseveration and preoccupation". It is concluded that "*no common meaning* can be discerned, but instead a number of ambiguities and contradictions have become evident. The term has been found to correlate with different things." Consideration of this list teaches, however, that the "different things" are likely to be different fields of psychological processes in which selectivity can be active: problem solving, perception, social relations and motivation. Discerning broadly, set, perseveration, hypothesis and determining tendency have been mainly applied to problem solving and learning. Attention, anticipation, and expectancy are used foremost in perception. Finally, terms like tension, need, vector and preoccupation have a clear connection with motivation and social relations. So, the manyfoldness of selectivity appears in a striking way; selection seems intrinsically combined with the just mentioned factors. Always "something" must be selected and what is going to be selected is always determined by some motivational or habitional background. Speaking about selective perception, selective learning etc., avoids the danger of handling the concept in a formal or animistic way. On the other hand this usage may explain the fact that "no comprehensive theory has yet appeared that synthesises this array of facts" – i.c. of set – (Allport 1955). If the data on selectivity in the various fields have some common background this should still be possible however. If the relation between selection and the specific field is expressed too closely in terms of the latter, a common background – if it exists – may be obscured.

The recognition of the importance of the selective principle and of the need of a wider incorporation in the theoretical formulations has been growing since world war II. Three reasons are present for this trend.

1. Developments in neurophysiology. The position of classical behaviourism was that the nervous system consisted in fact of a collection of neural routes leading from receptors to effectors. Only if excited by incoming stimulation would they become active. Recent investigations have shown that "the brain is continuously active in all its parts and an afferent excitation must be superimposed on an already existent excitation" (Hebb 1949). In this way, the original reluctance to accept selectivity as an intervening variable between stimulation and motor action on the basis of neurophysiological arguments, has been removed. The central brain activity has even become an urgent problem in neurophysiology itself, which has a clear effect on the psychologists views as far as the theoretical importance of selectivity is concerned.

2. The closer relationship between the study of personality, perception and learning. This culminated in the late forties in the "New Look" movement. Investigations on the role of the perceiver in perception emphasised the importance of motivational and habitional factors in the perceptual process. Experiments were carried out for instance on the relation between perception of ambiguous stimuli and personal values (Bruner and Goodman 1947) and on the effect of familiarity on recognition thresholds of words (Solomon and Howes 1951), which seem to point to the existence of prevailing hypotheses or categories – facilitating or inhibiting the response. Bruner's theory was called the "hypothesis – information-check" theory (Bruner 1951), to indicate that the perceiver disposes of a pattern of expectancies – "hypotheses" – about what will appear.

Some of the expectancies are due to short term experience, for instance during an experiment. Others come from long term daily life experience, e.g. the grouping of furniture in a familiar room. Finally, expectancies can be derived from values and needs. Thus, stated generally, the organism has a "perceptual readiness" before the actual stimulation has reached his senses. (Bruner 1957).

The work on set formation in learning and problem solving experiments, is more or less in the same line. A set to respond according to a special solution strategy can be formed in the course of training on a certain problem – e.g. the jar experiments of Luchins – which inhibits more or less the readiness to consider other solution possibilities. Once a set has been developed, the question arises how to overcome it again. Subjects who are strongly bound to a pattern of sets, appear to be highly ranked in rigidity tests and during the last decade much work has been devoted to the relation of set formation, rigidity and personality. (Rokeach 1951; Frenkel Brunswik 1949; Luchins and Luchins 1950; Sanders 1956).

3. A final development of research on selectivity was stimulated by *many practical problems in the human engineering branch.*
Questions arose about the optimal time a radar operator could do his watchkeeping task, without decline of performance. Also about the effects on performance of environmental stresses, such as noise, temperature etc. Data were wanted on fatigue, on the apprehension of simultaneously presented messages, on sensory deprivation, on convenient arrangement of objects on a panel, on strategies in scanning displays, and the list may be continued.
All these questions are strongly related to selection and rejection of stimulation, for in most of the situations, certain stimuli must be selected in favour of others. The research in this area has led to another theory about the selective principle, i.c. the filter theory of Broadbent (1958). The latter theory deals especially with the perceptual aspects of selectivity. The set to respond in most experiments is determined by instructions, instead of by the existing background of conditional probabilities of past events – categories, – values or anything else. The theory deals with questions about the maximum capacity of the organism in the selective process, about the effect of shifting between different senses during the selection of stimulation, about "distraction" by non relevant stimuli. In general, it deals with the structure of the selective process.

We have briefly touched the three major theoretical post-war trends on selectivity. In addition to these, there are several other indications of increasing interest in this topic. Some papers have appeared with the aim to incorporate "attention" in the Hullian and the Gestalt approach. (Berlyne 1951; Köhler and Adams 1958).
Other theorists recognize that their formulation "has little to say about attention or selective perception, but this remains to be worked out" (Gibson 1959). Another sign of the interest from the research side was the appearance of a "Bibliography on Attention" from the Wright Air Development Centre (Kreezer, Hiel and Manning 1956). Finally, the facts of set and selectivity have been treated extensively in the volumes on perception by Vernon (1952) and by Allport (1955. Ch. 9, 15, 16).

In spite of the accumulating work, however, specific knowledge on selective phenomena is still largely non-existent. In fact, systematic research has only recently started within the framework of the theories which have been mentioned. And, although the philosophical prejudices have largely been removed, the problem to handle selectivity in experimental research has not been satisfactory solved. Furthermore the terms attention and set – which are frequently used to indicate selectivity – have a great historical burden. To get a deeper insight into the difficulties we will continue with a concise historical survey on the theoretical connotation of these terms.

2. *The classical approach to attention*

The bond between selection and attention stems from the early days of psychology. This is clearly expressed in the work of James (1890), who defined attention in terms of selection and who also composed a kind of experimental research program.

The definition runs as follows: "Attention is taking possession by mind in clear and vivid form of one out of what seem several simultaneously possible objects or trains of thought". From this the relation with selectivity is obvious: one object or train of thought is selected and the other possible ones are rejected.

But there is more, for attention is also related to a "degree of intensity". This conforms the common sense opinion, in which a person's state of alertness is indicated by means of attention. One can be more or less attentive towards a certain matter.

So attention has two sides: selectivity and intensity. Especially the latter aspect would be measurable as a continuum. Selection can be described in qualitative terms. One may determine what is selected in a given instant and what in the next one. Nevertheless there seems to be at least one quantitative aspect since it might be measured how much stimulation is – or can be – assimilated at the same time. So – according to James – a major problem in selection is, to what extent two tasks can be performed at once.

This seemed to be a fair and promising basis for further research but unfortunately progress remained minimal for a number of decades. The main reason for this lack of progress was the general tendency to separate the selective aspect from the intensity aspect in the definition of attention.

In the classical theories – Wundt, Titchener and Müller – the intensity

aspect of attention was taken as the heart of the matter. Although this approach may seem permissible at first sight, it led to great difficulties. Especially the problem arose how to discriminate between attention and the perceptual act. In Wundt's theory, for instance, the difference between attention and apperception is difficult to trace. Attention was defined as "the state which accompanies the clear apprehension of a mental content and which is characterized by special feelings". The predominant feelings are mainly those of "being occupied" and of "facination" (Leidenschaft) (Wundt – 1896, 1911).
In comparing this definition with that of James, it is striking that the choice aspect has largely disappeared. The mental content is looked upon as something "given", without the consideration of alternative contents. Apperception is defined as "the action by which a mental content is clearly apprehended". The only distinction between attention and apperception is that the former refers to the accompanying state of feeling, while apperception is used to indicate the event itself.
Yet we must recognize that the selective side of attention is not completely absent in Wundt's formulations. His thesis that only a limited number of images has access to consciousness at a given time (span of attention) implies something like selection. This side of Wundt's theory is extended by the discrimination of the "Blickpunkt" and the "Blickfeld". These concepts indicate mainly a difference in the degree of clearness in which the images are apprehended, being maximal in the Blickpunkt and increasingly vague in the Blickfeld. Only the images in the Blickpunkt are apperceived, according to Wundt. The reason for the distinction between Blickpunkt and Blickfeld was the experience that, next to those images that were clearly apprehended, there was "something more".
Another aspect of selection within the Wundtian theory, was the possibility to dissipate and concentrate the Blickpunkt: it could be concentrated – or narrowed – with the result that the number of images, simultaneously apperceived, decreased at the gain of a higher clearness of the remainder. Dissipation occurs if the Blickpunkt is widened; then more images enter with a loss of clearness however. Wundt illustrates this point with the observation that normally one can recognize several words at a single glance. In determining the specific form of one letter, however, the other "are withdrawn in semi-darkness".
Although the concepts of dissipation and concentration stimulated some research within the Leipzig school – e.g. Wirth (1907), Kästner

and Wirth (1907) – the basic questions about selection did not enter the picture. Mainly because the element of choice was consistently left out. It is curious that, when the choice element was inherent to an experimental task, the results were not discussed in terms of selection. So experiments on prior entry – "Komplikations-Versuche" – were related to "time-sense", instead of to "an attentive predisposition favoring earlier clear perception of one signal" (Boring 1950).

The trend to neglect the selective aspect of attention is still stronger in Titchener's theory. Here attention was reduced to a mere attribute of the sensation. Besides intensity and quality, a stimulus could have a certain degree of sensory clearness, or "attensity", Attention was defined as the "sensory motor affective reaction of the organism to a stimulus" (Titchener 1910).
Again, the relation between attention and the perceptual process itself became a very urgent problem. To illustrate the problem, we can mention that during the twenties many publications were devoted to the question of distinguishing between attributive – i.c. „attentional" and cognitive clearness of the sensation.
It was proposed by Dallenbach (1920) to eliminate all cognitive elements in the experiments on attention in order to get an approach to attributive clearness. This resulted in verbal reports, obtained by the use of meaningless stimuli. The reduction to "sensory clearness" caused, in fact, attention to become a meaningless concept.
Very typical was the way the Cornell investigators looked upon the question of "span of attention". It was concluded by Glanville and Dallenbach (1929) that "range is not a proper question to set in attention. The attentive consciousness is an integrative whole and as such the range is always one – namely a certain level of clearness. Questions concerning the number of contents that may be simultaneously experienced are questions that concern cognition and not attention". Now it is admitted that the "span of attention" is rather a question of maximal cognitive capacity. Such was already the opinion of James and this is also held in modern literature – e.g. Miller (1956). Nevertheless the very fact that the human organism has a limited cognitive capacity is of direct importance: it asks for selection as soon as the organism is overloaded. This was not recognized by Titchener and coworkers, due to their experimental method and their definition.

Similar difficulties arose in the theory of Müller (1923). Again the intensity aspect of attention was dominant in this view. As is known, the Gestaltists had violently attacked the mosaïc theory of the atomists. Müllers theory may be regarded as a final attempt to defend this view. It is stated that attention may work as a kind of chemical katalysor, giving the Gestalt to a complex of elementary images. Directing attention towards a stimulus, the nervous processes are facilitated, enabling the appearing synthesis of the elements. Instead of an attribute of the sensation, attention is taken in this view as a formal brain activity. Although this is the opposite of Titchener's view, Müller arrived at the same difficulty, namely the identification of attention and cognition.

The view has been severely attacked by the Gestaltists (Köhler 1925) who stressed that the Gestalt should be considered as something "directly given," without needing a further explanation in terms of attention. Rubin (1921) had already published his paper on "the non-existence of attention," arguing that attention is used as a mere "ad hoc" concept, a deus ex machina in the explanation of perceptual phenomena.

Metzger (1954), discussing Müllers theory, stated: "attention in fact, does not mean any more than wakefulness and being directed towards a special sensory field. In Müllers view, attention does not cope with the experiences the attentive man gets from his own behaviour" and "according to Gestalttheory, attention may cause a splitting up of the Gestalt by analysis, while it synthesizes the percept in the atomists views". Criticisms of this kind highly restricted the influence of Müller's theory and it is only mentioned in this context, to illustrate how the attention concept had come into a deadlock: continuously the theorists shifted away from the original common sense meaning, in which direction and intensity are fully integrated moments.

This error cannot be considered as exclusively adhering to the classical "consciousness" theories, for the immediate successors of James also failed to treat attention in a fruitful way. Again attention was taken exclusively in the sense of degree of intensity. It was suggested that this factor should be approached by means of measurement of performance and reaction time (Mac Comas 1922, Wells, Kelly and Murphy 1921). Performance and attention were confounded however, sothat different tests, in which it was attempted to measure, say, distribution of attention, did not correlate with eachother (Neill Mc Queen 1917). Other investigators restricted their aim to the measurement of inten-

sity within one task. According to the common sense opinion, attention must decline after a long workperiod, since the subject gets tired. In this way it was expected that performance would decrease as a function of workspell. In fact, this was not confirmed by experiment. In a study by Arai, for instance, subjects worked eight hours at a stretch on a mental arithmetic task, without any significant decline. (Thorndike 1914). Thus, the general suspicion against the notion of attention, that was already present in behaviorists circles, was extended to the concept of mental fatigue. Both attention and fatigue seemed to be unmeasurable (Musico 1921).
The doubts on this point were again strengthened by the failure to show distraction phenomena in the experiment. The idea that environmental stresses, like noise, high temperature etc, exert a negative effect on the intensity of attention – and therefore on performance – was not confirmed.
The consequence was, that any attention concept was abandonned; the common sense opinions were considered as false.

3. Set and attention

It has been described in the previous section how the concept of attention came in a deadlock and that it was rejected by Gestaltists and Behaviorists. No re-evaluation of the concept took place, until a few decades had passed. In the mean time some investigations on selective phenomena were carried out, though not very systematically. As an example we can mention Külpe's work on "abstract behavior" (1904), in which it was shown that perception can be affected by instruction. When instructed to notice form qualities of the stimulus, other aspects, like colour, were reproduced less well. The subjects could be "set" towards perceiving certain qualities rather than others.
Set is defined by Allport (1955) as "the preparatory or facilitating condition of the organism that precedes, accompanies, or may even outlast the completely executed overt behavior or the act of perception. The act, implied in the set, will be brought to complete performance; all other acts, barring intruding circumstances that might impel a chance, will be excluded". Stated in this way, set is synonymous to selectivity, including those mechanisms that determine what is going to be selected. To the Hullian behaviorists set equals habit, if it has been learned and drive if it is innate. As was done in the introduction we can speak about a "pattern of sets", when we mean a pattern of

attitudes or traits – in the sense of Allport (1937). So far the Bruner approach towards selectivity is engaged with the effects of sets on perception.
On the other hand, a set can also be a very peripheral matter, for instance when the subject is instructed to deal with certain stimuli rather than with others. In general the term "set" has no pronounced character and it has rather served as a vague reference to the factors just mentioned. As said, a theory of set is absent and also Gibson's doubts about the usefulness of the concept were mentioned (see page 3).
Now, in more recent formulations, there has been a tendency to indentify attention with set. So Guilford (1946) defined attention as "the process of selection of what is going to be observed", which formulation is very near to the Allport definition of set. In Hebb's definition attention and set are also similar: "The facilitation of one phase sequence on to the next" (Hebb 1949).
In this way, however, the selective aspect of attention is detached again from the intensity side – although to the other extreme in comparison with the classical theories. The objections against this line of thought are obvious: in many automatized actions, where strong patterns of set are at work, we cannot speak of attention in the original sense of James. In fact the whole "new look" movement has been dealing with "set" phenomena in which no attentional aspect can be discovered.
Instead of an identification of attention with the perceptual material, here attention is getting more or less the meaning of underlying mechanisms of selection. An identification of set and attention seems dangerous for this reason. The terms may be rather used to discriminate between two supplementing aspects of selectivity. In "set bound" selection the actions run off without being sustained by external stimuli or inner control. To explain such processes we would never be tempted into the homunculus assumption! In speaking on attention, sustentation seems essential however. It is true that "attention bound" actions can include a pattern of sets but it seems impossible to describe this class of actions merely by set.
This conclusion is also drawn in a recent paper of Brown (1960). He remarks: "It is suggested that attention is directed towards a problem and not necessarily to the task at hand". Hebb arrives at the same idea in his 1955-paper, especially as a result of the findings on arousal. (see page 15).

4. *The measurement of attention*

In relation to selective phenomena there remains the crucial question whether adequate ways of measurement can be found. The development of a theory which exceeds the phenomenal and common sense level, is dependent on operational dimensions, where adequate quantification is possible. In the preceding sections we have seen the phenomenal startingpoint of James with respect to the selective principle and several theories have been analysed in relation to his postulates.
However, whether James' description is useful can only become clear, if it leads to adequate methods of measurement. This means that intensity of attention should be only measurable by reference to selection of stimuli.
It has been shown that the early methods had largely failed: whether measured introspectively or in terms of objective performance, the danger of identification of attention with perception was urgent. As Bills (1931) stated: "The loss of meaning of the word attention was due to its identification with the conscious effect, rather than with the process producing that effect". The experiments of Bills (op. cit) show, that – avoiding this danger – quantification of the degree of intensity is possible and indeed in terms of selection. The importance of this idea was not immediately recognized and, in a sense, Bills paper was rediscovered during and after the second world war, as the research on attention got its strong impetus.
The experiment went as follows: in a study on colour naming, the subjects responded continually since after every response a new stimulus was immediately presented. Analysis of the reaction times showed that short pauses occurred from time to time, during which no response was given. The pauses – "blocks" – increased as a function of time producing a greater irregularity in the flow of reactions. Moreover, there was a consistent tendency for errors to occur in conjunction with the blocks, suggesting that the cause of blocks (and errors) lay in a recurrent low condition of mental functioning. The effect did not lead to a decrease in the number of reactions, since the pauses appeared to be levelled out by more rapid reactions. So it was rather an effect of variance than of mean.
This result – that in fact had already been obtained by Woodworth and Wells (1911) – was confirmed by Broadbent (1953), who has also provided a theoretical framework. Wondering what happens during the blocks, Broadbent holds that the selection of task stimuli is momentary

interrupted. The longer the subject is engaged with the task – i.c. colour naming – the more often this appears to happen, pointing to an increasing trend to shift away from the task. This "shifting away" can be either a matter of selecting other stimuli or it may be due to momentary blanks (Broadbent 1958).

Assuming the former theory, which seems most plausible in view of the experimental results (Broadbent op. cit), one has arrived at the idea that, during the task, there is always a trend to select task stimulation and one to shift away to other-irrelevant-stimuli. The strength of these trends can be measured by estimation of the number of blocks over a certain period of the task. The more shifts, the less strong the tendency to deal with the task – or the less the intensity of attention towards the task. After some time of work "the selective filter becomes satiated of selecting the same kind of information" – says Broadbent (op. cit.).

So, in fact, this theory suggests that intensity of attention can be measured behaviorally by considering the degree to which one tends to select task information continually. This can be also illustrated by other situations, where involuntary rather than voluntary attention is involved. It was found by Karslake (1940) that the ranked "attention-value" of a number of objects correlated highly with the number of eye fixations, made at each of them. Thus, the object that was perceived "most vividly and clearly" was also the one, which was fixated most frequently by the eye. On the other hand, the relation between number of eye fixations and the area of largest "attensity" in Titcheners sense – and thus detached from cognitive elements – was shown to be absent (Guilford 1936, Mc. Millan 1941). "Attensity" did not correlate with the operations of the eye.

A striking difference between the classical methods and the one just described is that in the former one continually aimed at determining the intensity of attention in one particular moment, while the latter method emphasizes that intensity should be measured by considering a whole sample of subsequent selective acts – eye fixations, reactions and the like. This time-element is indispensable and determination in one moment is behaviorally impossible: in that moment the stimulus is either selected or not.

In the classical theories, the time-element was treated apart from the level of clearness in the topic of "duration of attention". Usually a stimulus was presented to the subject and, by pressing a key, he had to indicate when his attention wandered away from the test-object.

According to Le Roy Billings (1914) this always happened within a few seconds. Accepting the introspective methodology of this experiment for a moment, the finding is not surprising: in selecting the same stimulus during successive selective acts, the selective filter will rapidly become satiated. Since no new elements appear in the "task", the tendency to shift to irrelevant information will be predominant after a few seconds. If more complex stimuli are presented, more time will be needed to reach this state, as was also found by Le Roy Billings. Such inspections are not comparable however with continuous reaction tasks where new stimuli are presented every time. In the latter approach duration and intensity of attention are alike.

Apart from the "blocking" method, we have to discuss psychophysiological measurements of intensity of attention. It has been known for a long time that the state of alertness is correlated with certain physiological variables as muscular tension, skin conductance, heart beat rate, breathing etc. Using such variables as measures, a number of investigators, belonging to the "energetics group", have stressed the importance of the intensity dimension of behaviour. (Duffy 1951, 1957: Freeman 1948). For instance, experiments on the effect of induced muscle tension on performance seem to indicate, that work improves if an optimal degree of tension is induced. (Courts 1942; Bourne 1955). On the other hand, these variables proved to be less useful as methods of measurement if the task was perceptual rather than motor (Bartley and Chute 1947). The relation between the E.E.G. wave pattern and the degree of alertness seems to offer more possibilities in this direction. States of deep sleep, light sleep, relaxed wakefulness and highly alerting conditions show different wave patterns varying from large low frequency waves to a predominance of beta waves. Moreover "there is also a change from a regular synchronized appearance of the tracing to an irregular desynchronized tracing". (Malmo 1959). Recent findings also stress the importance of the ascending reticular activating system as an arousal or activation centre in the brain: "Lesions in this centre abolished the wave pattern of the E.E.G.and produced a behavioral picture of lethargy and somnolence". (Malmo 1959) Interesting for behaviour theory is the idea that there is an optimum of arousal in order to produce optimal performance. When the arousal system is overstimulated, performance decreases again. According to Hebb (1955) and Malmo (1959), arousal is synonymous with the "general drive state" – so without the steering component.

Arousal is considered as an energiser, not as a guide, although it is clear that both factors cooperate in behaviour: without any arousal, no selection of stimulation takes place. Which stimuli are arousing and which are not, is not decided upon by the arousal centre itself, but by the selective mechanism and its underlying stimulators as habits, needs, motives etc.

In Hebbs terms (1955): "The thoroughly familiar arouses a well organised phase sequence: the very fact that it is well organised means that it runs its course promptly, leaving the field for less well established sequences". Only the latter – referring to less established memory traces – will evoke perceptual selection in the proper sense, which may be expressed as a highly frequent reciprocally neural firing between the arousal centre and the phase sequence in question. Novel stimuli should have a high attention value in this way, which has been reported indeed. (Berlyne 1951).

This account deals mainly with phenomena of involuntary attention. As to voluntary attention the interrelation between arousal and selection is even clearer. The level of arousal must be maintained for the bigger part by "internal reverberation" in such situations (Hebb 1949) and the arousal centre is much less stimulated by the outer events than in cases of involuntary attention. Monotonous tasks therefore, will tend to decrease the arousal level with situations of perceptual isolation as an extreme (Bexton, Heron and Scott 1954).

The arousal theory can be considered as an important modern approach to attention, since it integrates behavioral and neurophysiological findings. From the measurement point of view it is important that it is possible to approach the intensity of attention by means of the E.E.G. records, so that the operational handling of the concept is promoted.

How widely this technique makes sense in the study of behaviour is still difficult to determine at this moment. Especially the correlation between changes in E.E.G. wave pattern and the course of performance-blockings – will be of interest. This has been investigated by Drever (1958) who measured performance in a vigilance task simultaneously with the E.E.G. The result was disappointing since no difference in the wave pattern could be shown between moments that signals were detected or not.

But perhaps this result is natural since the missing of a sign does not seem related to a momentary state of low mental functioning (paralysis theory), but rather to a state of being occupied with something else. (distraction theory). The paralysis theory predicts changes in the

E.E.G. record during blocks, since the general intensity level of attention is supposed to be low. If blocking is explained as a consequence of distraction, arousal may be equal, while the direction of attention has changed. This will not appear in the E.E.G. record, since it measures only intensity. In this way, the observation that physiological and behavioral measures disagree in many cases in the field of attention (Drew: personal communication) is likely to be again due to the fact that – physiologically – intensity and direction are separated, which has been shown to be impossible in behaviour. The arousal theory has stressed this point.

B. THE STRUCTURE OF THE SELECTIVE PROCESS

5. *The filtertheory of Broadbent*

It has become clear from the foregoing that knowledge on the selective principle can progress rapidly if more is known about the structure of the selective process, as it goes on in the sequence of actions. We have seen that intensity of attention may be measured properly by this means and speaking more generally – if we could find out which and how much stimulation is selected in a given instant, we could say a great deal more about the momentary interaction between stimulation, intervening factors and responses. As long as knowledge on this rather formal aspect of selectivity is insufficient, incidental data about attention and set may accumulate, but systematic progress is improbable.

This can be drawn as a general conclusion from the foregoing analysis. It seems an important result, since it pinpoints our interest to this side of the problem: what is known about the selective process. It has been the great merit of Broadbent, that he has provided a theoretical framework, which contains a promising start of the description of the selective process. His formulations were touched upon already in the introductory section and in that on the measurement of attention. In the present section we will describe the theory more detailed.

According to Broadbent selection of stimulation is imperative since only a limited amount of stimulation can be assimilated at a given instant. The process can be represented by means of a single channel communication system.

This notion is important with respect to the classical question, whether or not two things can be done at once. The classical studies had provided ambiguous results on this point. In the experiments of Binet (1890), for instance, subjects were instructed to perform a mental arithmetic test in combination with the rythmical pushing in of a balloon with intervals of a second. There proved to be a gain of time if the two tasks were carried out simultaneously in comparison with two single performances. The gain was small in the beginning but increased as a function of training, which may have been due to automation of the pushing task.

Other research dealt with the question, whether two simultaneously presented signals could be assimilated at once. This had been investigated already in the early studies on prior entry and more recent German investigators were also occupied with this problem (Mager 1925, Eliasberg 1930, Pauli 1930, 1937). They arrived at the conclusion that only one signal can pass at a time. The second one has to wait until the first is assimilated. After World War II this work was carried on by Broadbent and coworkers and by the investigators on the so called "psychological refractory period" (see Chapter 3 section 4).

A second main feature of Broadbent's theory is that the capacity of the transmission channel is not determined by structural features of the stimulation at hand but rather by its information content, which depends upon the number of alternative stimuli which can possibly appear. If stimuli do not contain information or if a group of stimuli is easily recoded – as in completely familiar situations – they can pass the channel without requiring much of its capacity. Thus the importance of the information concept is especially clear in relation to completely "set bound" actions.

According to Broadbent the incoming information has to pass a selective filter in order to be processed. The non-relevant information is rejected by the filter and, moreover, parts of the relevant signals cannot come through if the total amount of relevant information exceeds the limits of the transmission channel. Although in a different terminology and theoretical background, this point has some resemblance to the Wundtian notion of "Blickpunkt", which was also considered to have a maximal capacity. Dissipation and concentration of attention return in the modern formulations by the finding, that if too much information arrives, the signal can be transmitted in a more global way (v. d. Geer and Levelt 1963). A further hypothesis of Broadbent's theory is that the intake of information happens discontinuously: "We might suggest that the incoming information can only enter the perceptual system in segments of a given length" (1958 p. 280). – See also Hick (1948) and Welford (1960). This postulate may seem incompatible with James statement of the stream of consciousness. The fact that the processing of information has a continuous character in experience is not decisive however, since the discontinuity may remain unnoticed. It was found by Biel and Warrick (1949) that, when a timelag was inserted between the moment that a control is handled and the moment that the effect of this action became visible on an indicator, no discontinuity was experienced as long as the delay was less than 75 milliseconds. So, if successive perceptual samples follow each other rapidly, it is likely that the discontinuous character is not noticed.

A beautiful example of a process that proceeds in discrete steps, while it is experienced as continuous, is encountered in reading. Instead of sweeping smoothly across a line of print, the eyes show a series of fixations at several points along a line. During each fixation a sample of words is taken in, the actual quantity being dependent on various factors, such as practice and difficulty of the material (Woodworth and Schlosberg 1954). It seems a fairly plausible working hypothesis that the intake of information always occurs in successive steps.

The way the information reaches the senses is not indifferent for the success in transmission, according to Broadbent. If two messages are presented to both ears simultaneously, they can be handled with some success if the total amount of information is not too high. If the messages are given seperately, one to each ear – dichotic presentation –, one message is almost completely lost (Broadbent 1954). Even a change in language in the neglected message is not noticed. Highly affective elements – as calling the subject's own name – can, however, break the attentional bond to one ear (Moray 1959). So, if two messages must both be responded to, there is no advantage in dichotic presentation compared with binaural. There is an advantage if one message has to be ignored. Shifting attention from one to another sensemodality seems to take some time, which may lead to a decrease in efficiency, when visual and auditory information is presented simultaneously, and when both messages must be responded to.

This account strongly suggests that information, which does not pass the selective filter is blocked almost completely, though not necessarily altogether. There remains some vague entrance of not-accepted stimuli, which is clear from the finding that affective stimuli are noti-

ced. The subjects also notice changes in formal characteristics – e.g. change in voice – in the dichotic listening situation.
Furthermore, a recent investigation of Broadbent and Gregory (1963) suggests that blocking is not complete, although the threshold is highly increased. We may conclude that however much one is occupied with a task, there is always some space left to detect relevant non task stimulation. In fact this idea reflects to a great extent the Wundtian distinction between apperception and perception – the latter considered as the experience that, apart from the apperceived material "there is something more".
Although some details of Broadbent's argument are disputable (see next section) the theory is a quite promising approach. It should be said that the further theorising in this study is largely founded on this pioneer work. Although it does not imply that measurement of the selective process has become a simple matter, a firm basis for further research is now available. In the next section, we shall discuss some aspects of his theory which are especially concerned with the measurement of the selective process.

6. On the measurement of the selective process

As to the measurement of the selective process, two postulates of the filter theory seem essential i.c. the single channel assumption and the idea that the intake of information happens in discrete samples.
The latter hypothesis is especially important, since it pinpoints the approach to the selective process. Measurement of the selective process becomes identical to measurement of the discrete selective act or, as Broadbent says, the perceptual sample, The advantage of this shift is that we can direct our research to specific questions about the characteristics of the selective act. The selective act is here defined as the discrete event – strictly limited in time – in which a certain amount of information is selected in order to be further processed. According to the single channel view the amount is limited. In principle, the selective act – or the perceptual sample – can contain "outside" information as in inspection work and other perceptual tasks, as well as "inside" information, as in thinking, day dreaming, rehearsal etc. Both ways of process are combined in feedback activity in which motor actions are visually controled – e.g. tracking work.
A great difficulty with respect to the selective act – and therefore with respect to selectivity in general – is however that the existence of the

selective act is still a hypothesis, although – in view of the experimental data – a plausible one. At the present state it is not possible to measure its characteristics directly. At best, certain qualities can be inferred. The operational anchorage of the perceptual sample is one of the major problems in Broadbent's study.

Rapid progress in this area would be possible if more was known about the time taken by a selective act, especially if this should prove to be relatively constant in various situations. The latter view is defended by Broadbent, although he admits that "it cannot be regarded as even tentatively established". The time needed for a selective act is thought to be about $\frac{1}{3}$ sec. This quantity arose from the discussion of some experiments from Cherry and Taylor (1954) and Schubert and Parker (1955).

When speech was presented alternatively to one ear and the other, a dip in intelligibility existed if the speech was in one ear for about $\frac{1}{6}$ sec. The same dip was found if all speech presented to one ear was left away, sothat 50% of the speech was presented to one ear only, with evenly spaced interuptions. A further finding concerned the odd fact that the dip decreased if in the alternating condition noise was inserted at the times that no information arrived at one of the ears. Assuming that information is sampled during $\frac{1}{3}$ sec before transmission takes place and assuming that the shift from one to another ear cannot take place during the sampling (see page 26), one may explain why the dip occurs in the two ears case. In the one ear case the dip should appear for the same reason. "The fact that the speech is present for only the first half of each sample impairs the chance of a correct decision as to the nature of the sound delivered to the ear" (Broadbent 1958 p. 214). Apart from the "ad hoc" character of this statement, it is also not clear why noise insertion should recover intelligibility in the two ears case. The remark that "noise insertion may blur the dip" (p. 215) does not clear this point.

The constant time length is further applied to explain some phenomena met in studies on the "psychological refractory period". When two signals are presented in rapid succession in order to be responded to, it has been found in some studies that the second reaction time is retarded in comparison with the first one, according to $D = Rt_1\text{-}I$ $(I \leqslant Rt_1)$, where D stands for the delay, Rt_1 for the first reaction time and I for the interstimulus interval. So, the delay takes a full reaction time. This is surprising, even in the light of the single channel theory, since one would only expect a blocking of the second signal during the central transmission period of the first signal. There is no reason why the peripheral conduction times are hampered. Assuming that a selective act lasts $\frac{1}{3}$ sec., a possible solution is offered, for in that case the second signal has to await the moment that the sampling time of $\frac{1}{3}$ is finished before transmission can take place. Occasionaly both signals can fall into the same sample, especially if I is short, and then no delay of the second reaction time in comparison with the first one is expected. In some studies, this is indeed found – Welford (1952, 1959) – but it is absent in others (Davis 1956, 1957, 1959). The lack of general occurrence of this phenomenon – called grouping – offers a difficulty to the idea of constant time length of the selective act. One would expect that, at small intervals ($\leqslant 0.1$ sec.), S_1 and S_2 would fall in the same segment most of the time, while this should *still* occur occasionaly at $I = 0.3$.

Moreover the reference to reaction time is fatal to the theory, since one would expect a similar process of finishing the selective act before taking action, in single reaction situations. If the stimulus arrival and the start of a perceptual sample, or a selective act, fall together, and Broadbent is vague on this point, we would predict at least a reaction time of $\frac{1}{3}$ sec., apart from the central organising time and the peripheral conduction. This is clearly not in accordance with the usual findings in reaction time studies.

Other negative evidence stems from work on reading and visual search. Assuming that a fixation pause of the eye reflects at least one selective act – and to the opinion of the author there must be some relation – we find that fixation pauses are generally less than $\frac{1}{3}$ sec., at least if the reader has some experience (Carmichael and Dearborn 1947). According to Buswell (1922) fixation time decreases as a function of education until a minimum has been reached at about the fourth grade of primary school. Learning effects are also found in visual search tasks like inspection of radar displays. White and Ford (1960), using untrained subjects, found an average length of .37 per fixation pause, while Michon and Kirk (1962) reported a mean duration of only .25 sec. when trained operators were tested.

Another main effect of training on the processing of information is that, with more experience, the material can be recoded into larger units – Smith and Miller (1952) – so that more information can be assimilated per selective act, when the subjects are trained. In fact, of course, the information capacity has remained constant, but the coding strategy has improved. It has been found, for instance, that the

number of glances per line decreases as a function of reading experience (Buswell op. cit). Sumby and Pollack (1954) found the same as a function of the degree of approximation to English.
Now, if the length of a selective act was really constant, we would predict that training effects are restricted to the latter class of phenomena and do not affect the length of the fixation times.
To save the constant timelength hypothesis, it might be argued that the fixation pause reflects more than the time taken by the selective act. It may include, in fact, the central transmission time of the material. In that case the length of the fixation pause will decrease as a function of experience, due to a shortening of the central transmission time while the constant timelength of the selective act can be retained.
The consequence of this argument is, at least, that the $\frac{1}{3}$ sec. period becomes untenable and should be much smaller. If one assumes however that the "constant length" approximates zero, it should be wondered if it makes sense to speak about the timelength of a selective act at all.
The alternative idea is that the length of the selective act is variable within certain limits and lasts until an optimum of data has been collected. The optimum will increase as the material can be processed more efficiently. In this way, it seems better to replace the question about the timelength of the selective act by the question as to how much data are sampled. The time problem remains very urgent in relation to the events in the transmission channel.
The duration of the process in the transmission channel is likely to depend upon a large number of factors, e.g. the amount of information that is transmitted, is likely to play a role. In that case the length of choise reaction times should increase as a function of the information load of the signal, as was found indeed in studies of Hick (1952) and Hyman (1953). In contradiction to their results are the findings of Leonard (1959) and Mowbray and Rhoades (1959). They failed to find an increase of reaction time, when the mode of response was well learned. In Leonard's work this was shown for tactual choice responses and in Mowbray's experiment for vocal responses to visual signals.
The results of the latter experiments show clearly that the emphasis in studies on information transmission should not be laid exclusively on the input side of the process – as has been the trend during the last decade. In transmission, the mode of output appears equally important. We can assume that during the transmission period the input is translated in response terms, which process is likely to run efficiently

when the response categories have been very well learned – so that even the reaction time becomes more or less independent from the information content. When key pressing is the mode of response the compatibility is likely to be much less in which case the information content will start to play a role (Davis, Moray and Treisman 1961).
Within the area of key pressing responses, the stimulus-response compatibility can still be varied, which will probably affect the degree to which differences of information content affect reaction time (Fitts and Seeger 1953). When the conditions are very bad it may even be possible that two selective acts become necessary: one to select and convey the signal and one to determine the correct response key. Much more research should be devoted to this important topic (see also: Deininger and Fitts 1955, Welford 1960, Bertelson 1963).
Next to the actual amount of information – with the restrictions as stated above – there are more factors affecting both the speed of transmission and the maximal capacity of the transmission channel. For instance the discriminability of the signal. The greater the "confusion value" between signals the longer the reaction time and the more limited the capacity (Crossman 1955). In terms of information theory this factor can be considered as an example of external noise. We may also mention the factor of multidimensionality, which will be discussed later in this section (see page 27). Finally the way of presentation itself is important: if two signals are presented, which both convey one bit of information, it is dangerous to say that they occupy an equal part of the transmission channel as one signal conveying two bits. This is also stressed by Broadbent (1958 p. 293).

The events in the transmission channel are likely to be highly important to the question of how much information is collected in a selective act. We can assume that, under normal conditions at least, the selective mechanism is "informed" about the efficiency with which information can pass the transmission channel. This may, at least partly, determine the amount of information that is sampled in one act. When the efficiency of several modes of sampling does not differ too much, subjects may be able to vary their "selective strategy". What is preferred in those cases can depend upon instruction or on individual sets.
For instance, when a number of relevant data is presented, subjects may either prefer to handle the material in successive small acts or to collect all data in one chunk – granted that the limits of the channel-

capacity are not exceeded. In the former case, the first selected material will be transmitted quite rapidly as opposed to a considerable delay in the transmission of the last selected part. In the case of "grouping". an average reaction time is expected to all items.
In the case of "successive handling," it is clear that the maximal capacity of the transmission channel is never used. It is suggested that in those cases the remaining capacity promotes a more rapid processing than would be possible in the case of grouping. Of course, this is only true for such signal-response conditions, where the transmission time is dependent on the amount of information.
If this idea is valid, it has certain consequences for the concept of "spare mental capacity". This notion has been used to indicate the spare portion of the transmission channel during performance of a task (Bornemann (1942), Brown and Poulton (1961), Brown (1962), Schouten, Kalsbeek and Leopold (1962)). In the experiments a main task is carried out together with a secondary task: the degree of performance in the latter is determined and taken as a measure for the spare mental capacity. This should not be considered as the difference between the maximal amount, which can be carried in a selective act and that amount which is actually processed. For, in fact, this remaining capacity is used efficiently, namely to increase the speed of the process. The concept seems only applicable if, in the succession of the selective acts, not all acts are needed to process the relevant material.
In such cases one may determine how many selective acts can be devoted to "irrelevant" information by inserting an additional task and by measuring how well this can be done in combination with the main task. Theoretically it is thought to be impossible to combine signals from different tasks in one selective act, without retarding the responses of both.
The concept of spare mental capacity only makes sense if the task has a strict temporal structure and if it does not require continuous attention – or does not fill every selective act. At a continuous informationflow – we must assume that an optimum of information is sampled in each selective act, so that no spare mental capacity is left.
In spite of this general evidence, little is known about the optimum number of data per selective act for different kinds of stimulation and about the various strategies the subjects may be capable of adapting. It is likely that in many cases the selective strategy will be prescribed – partially or completely – by the special characteristics of the experi-

mental situation, the physiological limits of the organism and the particular set of habits, which has been developed.

Due to this lack of knowledge, the time does not seem ripe to explain experiments, like those of Cherry and Taylor, in terms of successive selective acts. The best that can be said about the dip in intelligibility, when the speech is splitted up in parts of $\frac{1}{6}$ sec. duration, is that at this rate the speech is probably more difficult to code in the transmission channel. The $\frac{1}{6}$ sec. periods are slightly shorter than the time needed to pronounce a phoneme, which may be considered as a basic constituent of the coding process in speech. A syllable may have a similar function in written language. This idea includes the hypothesis, that successive parts of speech are not easily integrated, if not every part is meaningful in itself. This has indeed been found by Michon in an experiment on letterspan. A number of 12 letters of the second order approximation to Dutch was presented at once or successively in groups of 2, 3, 4 and 6 letters. The subjects obtained an almost perfect score if the letters were given in groups of 4 and 6 letters, but when split up in groups of 2 letters, the reproduction was only slightly better than when the intrinsic structure of the letters was random. Apparently the redundancy of the sequence was not recognized in the latter case and no combination of two successive groups was made. Michon remarks that "In no instance subjects have connected successive units and integrated them into larger chunks" (Michon 1962). The total presentation time in this study was always $1\frac{1}{2}$ sec and thus each group of letters was present for $1\frac{1}{2}$: n seconds, where n stands for the number of groups. Michon interpretes his results largely as a consequence of the temporal proximity. In the case of successive two-lettergroups the selective mechanism is not able to assimilate the rapid succession of the lettergroups adequately. On the other hand the possibility is open that the bad result is due to the fact that a two lettergroup of second order approximation has less chance to include a syllable than when 4 or 6 letters are presented.

If it is true that successive lettergroups or bits of speech are better combined if each group consists of a syllable, this will have consequences for our theory of the selective act. It can be suggested that several parts are integrated in one act, as long as the parts themselves can be easily recoded. If the latter condition is not fulfilled, the integration will fail accordingly. Instead of one recoded sample, a series of independent samples follow each other. Instead of one selective act for successive groups, each group starts to take a seperate sample. The selective mechanism is no longer "informed" about the most efficient way of coding in the transmission channel and regresses to a primitive strategy – being determined by the timelags between the lettergroups. At that point the proximity in time may enter the picture. Before the first sample is transmitted, the second and third have arrived already and after a short immediate memory storage, they deteriorate before treatment is possible. The latter point follows closely the view of Brown (1954, 1958) and Broadbent (1957) on the role of immediate memory in perception. The recoding process in the case of redundant groups is possible by means of a direct assimilation with the permanent memory (Sanders 1961).

Temporal proximity will evoke a more serious effect in visual than in auditory tasks. It is known that the visual sense modality is rather adapted to simultaneous intake of information, while successive handling is predominant in the auditory field. The phenomenon of subitizing, for instance, (Kaufman, Reese and Lord 1948) is typically visual and no auditory analogon exists. Nevertheless it is possible to train subjects quite adequately to the intake of successively presented visual material, as is very clear from the ability to receive visual morse messages. Optical signalmen have to learn the configurations in an assembly of successively presented visual signals (Sanders 1957). Simultaneous intake of auditory messages belongs much less to the physiological make up of the human organism. Masking and summation of auditory signals would already prevent this at the peripheral level.

Other preliminary indications about the structure of the selective act may be derived from research on the time needed to shift attention. This is expressed by Broadbent as: "A shift of the selective process from one class of events to another, takes a time, which is not negligible, compared with the minimum time spent on any one class" (1958 p. 249). The time to shift from one to another event, is thought to be about 0.2 sec. It is dubious, however, what is meant by an "event". If it is taken as a perceptual sample, it would imply that between two successive selective acts there always exists a timelag of 0.2 sec. This is highly improbable in view of the experimental facts (reading, speech, etc.).

The "class of events" might also be taken as a special property of the objects. Then shifting of attention would occur if one shifts from, say, the colour of an object to its form. The difficulty with this idea is that different properties of an object are found to cooperate to a certain degree in the transmission of information. Thus in the estimation of a number of black dots on a white background, it has been found that there are some 20-30 distinguishable categories of numerousness so that the subject transmits a little more than four bits of information. This is considerably more however than the usually reported maximum of about 3 bits per presentation at unidimensional displays (Pollack 1952, 1953, Hake and Garner 1951). The conclusion is therefore that the estimation of number may occur on the impression obtained from two properties of the display "Perhaps the two dimensions are area and density" (Miller 1956).

A similar increase in information transmission has been reported in other fields, where a "multidimensional display" was present – e.g. in discrimination of pitch and loudness of tones, being varied together. So, normally, the various properties of the object are likely to be coded as a functional unity – not needing a shift of attention. When explicit instruction is given however – as in the classical experiments of Külpe (1904) – different properties may be separated in the selective process.

The main research on shifting time stems from experiments, in which signals or messages are simultaneously presented to different sense organs. A visual and an auditory message for instance, but also two auditory messages, being presented each to one ear. Already in the German prewar work on attention, the investigators were convinced that in shifting from one sense modality to another, one would meet a socalled "attention step" (v. Kries 1913, Feilgenhauser 1917, Mager 1925. Pauli 1930). The interesting fact is that the shifting time, reported in this earlier work, corresponds quite closely with Broadbent's estimation, although Broadbent was not aware of the older experiments. Mager (op. cit.) mentions 190 ms. as the shortest attention step and about the same quantity is suggested by Pauli. Both experimenters compared single and dual reaction time to a visual and a tactual signal.

The recent research on shifting time stems mainly from Broadbent and co-workers. When signals are presented binaurally, a better result appears than if they are presented dichotically, under the condition that all signals should be responded to. But if one message has to be ignored, separation of the messages is more useful. This points to the existence of a functional separation of the ears (Broadbent 1957; see also page 18).

To shift from one to the other ear, a time of 0.2 sec. would be required.

This is concluded from an experiment where series of digits were presented dichotically; so two digits always arrived at the same time, but at different ears. It was found that reproduction always took place in such a way that first the digits of one ear were given and, subsequently, those of the other one. Pair reproduction was virtually impossible. The same effect was found if one series was presented visually and the other auditory and also if the two series were presented to the same ear, but with spectral differences in the pronounciation (Broadbent 1957). If the rate of presentation was lowered, pair reproduction became possible and this occurred earlier in the spectral differences condition (± 1 pair per second) than in the dichotic situation (± 1 pair in two seconds).
Now Broadbent argues that if perception of one digit takes about ½ sec., and the shifting time about 0.2 sec., the full circle to transmit two simultaneously presented digits takes about 1½-2 sec. in the dichotic presentation.
In the light of more recent findings, however, the generality of this theory is doubtful. Moray (1960) repeated Broadbent's experiment with the extension that the digit series were also presented "staggered" and "overlapping". So three conditions were compared: simultaneous (= = =), overlapping (=-=-=-) and staggered (—_—_—_—). Thus in the last condition, digits were presented alternately to one ear with equal time relations as in Broadbent's experiment. It was found that pair reproduction was quite possible now, which result is incompatible with Broadbent's theory.
Similar findings are reported by Gray and Wedderburn (1960), who presented words broken up in syllables or phrases broken up in words, with the constituents alternating between the ears. Lists of digits were presented simultaneously to the ear that was unoccupied. Reproduction according to ear of arrival proved to be as efficient as according to pair or meaning (i.c. words and digits). Both Moray and Gray and Wedderburn concluded therefore that the way of recall is presumably a question of selective strategy. It was admitted, however, that the preference might depend on the way of presentation and the kind of material. Both reject the concept of shifting time.
Also Broadbent and Gregory (1961) found that subjects – being offered a staggered list of digits – could recall in pairs or according to ear of arrival, even if the instruction about the mode of reproduction was given after presentation. So the selective strategy hypothesis was confirmed. Pair reproduction was impossible however, if one list was

presented visually. In this case reproduction of the auditory material preceeded or followed recall of the visual data.
So, from the present status of the research, it appears that switching from one sensory modality to another is probably a more difficult action, than switching within one sense modality. This is clear from the prewar findings, it has been found by Broadbent and it is also clear from the work of Mowbray (1952, 1953, 1954). Within the auditory modality, shifts of attention seem to be easier. Functional boundaries in the transition from one ear to the other only appear, when signals are presented simultaneously and when they belong to the same category. This is not easy to explain with the aid of the shifting time concept.
If a shifting process existed, we would expect it to occur more generally.
The different findings in dichotic listening may be compromised by reference to the prior idea that the auditory modality is not adapted to simultaneous intake of information. In a situation where digits are presented simultaneously, one selective act may be devoted to select the digits of one ear, while the remainder is temporarily stored and conveyed in the next one. The phenomenon that afterwards no reorganisation of the material was possible may indicate that – under these conditions – the interaction between successive selective acts does not occur as a matter of course. At a lower presentation rate the subjects are able to alter the selective strategy. Possibly a separate selective act is devoted to every digit. Since the temporal proximity of the digits has decreased, the unit from the other ear can pass the selective filter before the next pair of digits arrives. If the digits arrive successively – as in Moray's study – they enter again in the way the ear is used to. This will be sufficient to overcome the functional boundary and therefore the material is likely to be taken again in one bigger sample.
This explanation does not incorporate the finding of Gray and Wedderburn that pair reproduction is possible when the simultaneously presented signals belong to different cognitive categories. Apparently the functional boundary between the ears can be overcome in this way; perhaps since information from different cognitive categories is less mutually inhibiting. In analogy to the Gestaltlaws in perception, it may bring about a clearer contrast between the presented units, facilitating simultaneous intake.

Recapitulating, it seems to emerge from this discussion, that there is a series of interacting factors, which affect the structure of the selective process. Simultaneous intake of material, presented dichotically, is restricted due to a functional boundary between the ears. Whether or not simultaneous intake of the material can take place seems dependent on factors like categorial difference of the signals, the use of affective stimuli, the degree of temporal proximity and learning. All these factors – and probably a number more that are still unknown – are likely to interact and the result of this interaction is decisive for the question as to whether the functional boundary can be overcome. Between sensory modalities the functional boundaries appear to be stronger than within a sensory modality. This is clear from the finding that, under conditions where pair reproduction was possible in dichotic listening, it could not be accomplished when one list was presented visually. The functional boundary may be overcome however if the interacting factors are strong enough. Research on the hierarchy of these factors is highly needed.

Is it useful to maintain the idea of shifting time as long as different sensemodalities are involved? Again we would expect a rather constant general time loss, if such were accepted. As mentioned before, there is some agreement between the prewar research and the experiments of Broadbent about a time loss of 0.2 sec., when one is required to shift from one sensory area to another. One of the arguments for this 0.2 sec. period is derived from the blocking phenomenon in continuous reaction tasks. According to Broadbent (1953) blockings generally take a time of about 2 sec.; the block is thought to consist of twice a shifting time, a perception of the irrelevant stimulation and the reaction time to the relevant stimulus. Reserving some time for perceiving the non relevant information – ½ sec. after Broadbent's suggestion, – there remains an extra timecomponent, which reasonably fits the 0.2 sec. period to shift attention.

The whole idea is a construct however, and can never be used to prove the existence of a shifting time. Further the 2 sec. length of blocking is doubtful: there are reasons to suppose that Broadbent first defined a block as lasting two seconds and that this time is afterwards reported as a finding.

To make this point clear, we may compare Broadbent's definition of a block and the original use of the term by Bills (1931). The latter author has listed a series of conclusions about "mental blockings" i.c.:

1. In mental work, involving considerable homogenity and continuity, there occur blocks or pauses, during which no responses occur. These blocks occupy 2-6 responses.

2. Practice tends to reduce the frequency and the size of the blocks.
3. Fatigue tends to increase the frequency and the size of the blocks, producing a greater irregularity in the flow of responses, without reducing the actual number of responses.

Both the original finding of 2-6 responses and the conclusions about practice and fatigue stress the importance of an individual criterium to determine, which pauses should be considered as blocks and which not. Thus, a highly practised subject will show smaller blocks for the mere reason that his normal reaction time has been shortened. Broadbent's criterium of blocks is a generalised one however: those reaction times, that are longer than 2 seconds are recorded and they are considered as blocks – on an apriori basis.

Koster (1962), in a recent study on the effect of lighting on continuous performance, measured blocks according to Broadbent's criterium and also according to the original findings of Bills. In his data, reaction times exceeding 2 seconds were rare, while setting the criterium on two times the median reaction time, the results were comparable to those of Bills. Davis (1957) presented a simple visual and auditory signal in rapid succession to test the single channel theory. He found that the second signal was not treated before the first one had been reacted to, but no extra delay for shifting attention was found that approximated the 0.2 sec. period.

The results of both Koster and Davis are contradictory to the shifting time assumption for the mere reason that no time loss is present in the transition from visual to auditory information. As Moray (1960) remarks, there is no guarantee that subjects must have been shifting. The fact that in a certain category of situations auditory and visual information cannot be processed together, does not prove that we have to do with a – timeconsuming – shifting of attention.

Reconsidering this paragraph, it is realised that there is scarcely any valid knowledge about the characteristics of the selective act. As stated earlier: as long as it is impossible to measure the selective act in a more direct way, especially the amount of information that is sampled, we can make no considerable progress in the field of selectivity – at least not by means of behavioral methods. Alternative to direct measurement, we can only investigate whether certain general characteristics of the selective process can be detected. The foregoing pages have been devoted to such an analysis. Its value is highly restricted however, in view of the lack of systematic experimental evidence. Therefore, the description of the selective process in terms of selective acts runs the risk of ad hoc speculation. Such an undertaking only makes sense if the description has some predictive value.

7. *The selective process in the functional visual field*

Meanwhile there is a limited field of experimental situations in which – under certain assumptions – the contents of a selective act can be directly measured. We may refer to our earlier remark that fixation-pauses in reading and visual search can be supposed to reflect selective acts. The application of eye movement recording therefore will prove a great aid to the analysis of the selective process. The limitation of this method of measurement is of course that a shift of the eye is required after each perceptual intake. Although this requirement is a serious restriction – especially in view of the idea that the selective process will be highly dependent on the kind of experimental situation – it still seems very important to carry out a further analysis and to consider howfar the results fit the preliminary hypotheses concerning the selective process in the dichotic listening situations. The eye movements, made in a visual task and meant to shift from one to another source of information, can be said to be the only instance in which "shifts of attention" are clearly met. They take time and they can be measured. Furthermore it has been found that the visual threshold during saccadic eye movements is enormously increased, if the stimuli have a fixed position during the movement. In such cases perception is virtually impossible (Holt 1903, Dodge 1905, Latour 1961), so that the movement time of the eye is really used to shift attention. The objection can be raised that the object, which is fixated by the eye, is not necessarily perceived. Attention might be directed to something else. For this very reason, Wundt (op, cit.) distinghuished between the outer and the inner Blickpunkt. Although this introspective objection may be true, there is evidence that in normal performance, the aimed object is indeed fixated. Only when the subject is instructed to keep his eye fixated and to view objects peripherally the argument enters the picture. A discussion of intra-visual shifts of attention is not included in Broadbent's account. The reason may be that this theory is only engaged with the filtering aspect of selection. Incoming information is accepted, rejected, or temporarily stored by the selective filter and shifting attention equals shifting the filter. In eye movements the shifts of attention rather reflect a steering component than a filter component. The notion of

steering is a necessary complement; it refers to the observation that the subject is able to decide from which source he will select his information – by the very fact that he can move his eyes, his head and his body. The filter theory only takes into account a motionless subject with a fixated eye, who awaits the arriving information. Steering seems especially important to the visual modality and has also bearings on the tactual orientation. Due to the physiological organisation it seems less present in audition, smell and taste, although there are rudiments of orientating movements – especially of the head – which accompany audition and smell. The steering activities, meant to shift from one subject to another or merely to find an object, can be said to have the behavioral significance of a shift of attention. Restricting our argument to the visual modality, the activity of sampling information and shifting can be said to occur in the "functional visual field". This term is used in distinction to the "visual field" or the "statical visual field" both of which are defined as the range of spots that can be adequately covered with the fixated eye (Dubois-Poulsen 1952). In the last mentioned reference the "dynamical visual field" is defined as the range of spots that can be adequately covered by means of eye movements, head movements etc. This seems at first sight to be synonymous with the functional visual field. Dubois-Poulsen, however, states: "It is evident that this investigation is especially concerned with the physiology of the muscles of the eyeball and the neck". The emphasis is laid therefore, on the physiological aspects of the problem: in the statical visual field these are structure and the possibilities of the retina and, in the dynamical visual field, the physiological aspects of the muscles. Although it is admitted that physiological data about the visual system are highly important to the functional visual field, our main interest is directed to performance and behaviour. The functional visual field may be defined therefore as the spatial area, that has to be apprehended by the subject in performing a visual task.
Compared with the mass of psycho-physiological studies on the statical visual field, the knowledge about the selective process in the functional visual field is virtually absent. The many studies on eye movements are more devoted to the characteristics of the movement process itself than to selection of signals – apart from work on reading and from a few studies on selective strategy in visual search situations. Most of this work however, has been done in order to be applied and not with the specific intention of building a theory.
Nevertheless some interesting points have emerged, such as the phe-

nomenon of peripheral blindness, referring to the observations that considerably less eye-fixations are found in the periphery of a display than in the central part – a tendency which tends to increase as a function of workspell. Thus, the selective mainpoint – defined as the area where most eye-fixations take place – becomes more narrow as time goes on (Drew 1940, Bursill 1958, Michon and Kirk 1962).
It has been found by Baker (1958) that attention towards certain parts of the display can easily be biased by means of reference objects. This seems very important to the study of the selective process and will be discussed in greater detail at a later stage of this study (Chapter 4;3).
Another point, which is of direct interest to the analysis of the selective process, concerns the question of how performance in a visual task is related to the display angle under which the task is carried out. It can be said that each visual task – e.g. watching a panel – has certain spatial extensions, forming a display angle with the subject's position. We can safely assume that if the display angle is increased, the efficiency of performance will decrease. This is plausible for the mere reason that larger eye movements will be required to cover the area. Moreover, less effect of peripheral vision is expected as the information sources are more separated. It seems important to know how these psycho-physiological aspects are related to the selective process.
In the previous sections, we have said repeatedly that signals may be grouped in one selective act, so that they are transmitted simultaneously. We wonder to what degree of angular separation such a process is still possible. It may be that grouping is possible as long as the task can be done with the exclusive aid of peripheral vision, and that when eye movements become necessary, a succession of two selective acts – intermediated by a shift of attention – takes place. Besides, the introduction of other attention direction mechanisms – e.g. head movements – may exert an effect on the sequence of the selective acts. This area is scarcely touched by experiment, although it seems a promising entrance to the analysis of the selective act. Direct measurements of fixations and shifts of the eye can be obtained. Changes in the selective strategy – for instance if grouping is replaced by succesive handling – will probably result in a decrease of performance. In view of these advantages research on the functional visual field may yield valuable information about the selective process. This will be checked in the forthcoming experimental chapters. Chapter 2 will be devoted to some exploratory experiments on the relation between eye- and head movements, performance and display angle.

In chapter 3 the results will be discussed in terms of the selective process. In particular the problem of grouping versus successive handling of signals will be treated. Throughout this work only one experimental task will be considered. The question as to what extent the obtained results also hold in other experimental settings, is investigated in Chapter 4 and 5. The results are summarised in Chapter 6.

CHAPTER 2

PERFORMANCE AS A FUNCTION OF DISPLAY ANGLE

1. Review of some literature

As mentioned in the previous chapter, there are only very few studies dealing with the measurement of performance as a function of display angle. Those that have been carried out however, suggest that enlargement of the display angle is attended by an increase of reaction time and by a larger number of missed signals. There is also evidence that at certain display angles the search or inspection strategy of the subjects changes. From our point of view, the latter aspect is the most interesting and therefore it will be emphasised in the present discussion.

A change of selective stategy has been noticed especially by Corbin, Carter, Reese and Volkmann (1958) in a study on visual search. In their experiment a lightspot had to be detected that was presented somewhere on a screen. Two variables were introduced namely the display angle and the brightness of the signal. The subjects were free to view the screen peripherally or to use eye- or head movements. The results showed an increase of reaction time as the display field became larger and besides, it was found that for each brightness level there was a maximal range, where targets could be found rapidly. Beyond this maximum the variability of reaction times strongly increased, pointing to the occurrence of both rapid and slow detections. Depending on the brightness, the maximum range varied between 40° and 80°. The authors concluded that "the 40°-80° limit on an optimal performance suggests that the subjects' method of search changes and becomes less serviceable when he must search over wider ranges".

Another indication for a change of selective strategy at a certain display angle can be derived from an experiment of Fitts and Simon (1949). Subjects performed a "dual pursuit tracking task", so they were asked to hold two pointers in line with moving tracks.

The distance between the tracks was varied both in the horizontal and the vertical direction. Performance was measured in percentage of the time that the pointers were held correctly (see table 1).

TABLE 1 - Percentage of time of correct performance in a dual pursuit tracking task. (Fitts and Simon 1949)

Distance between tracks	Horizontal	Vertical
4 inches	61%	52%
8 „	49%	45%
12 „	44%	36%
16 „	40%	33%

The results showed a generally better performance in the horizontal than in the vertical direction, being more a constant difference than one interacting with the display angle. Especially in the horizontal condition, there is some tendency for a non linear decrease of performance since the difference between four and eight inches is larger than the difference between any of the other distances. This trend is not stressed by the authors however, and may be due to random variation. If significant, it might point again to a change in inspection strategy, when a certain display angle is exceeded.
One difference between the reviewed experiments concerns the fact that in the former an increase of display angle was attended by an increase of spatial uncertainty. The greater the visual area, the more possible places where the lightspot could be presented. In the experiment of Fitts and Simon on the other hand, no spatial uncertainty was involved. In a first approach to the effect of display angle, preference was given to the latter design, since in confounding spatial uncertainty and display angle an extra variable is likely to be introduced.
Thus, an experiment was carried out on the relation between display angle and the effect of noise on performance (Sanders 1961). The test was a continuous discrimination task, which lasted half an hour. After each reaction a new signal was presented, so that the speed of work could be determined by the subject. The signal consisted of two lights, that were placed under a certain display angle (20°, 94°). A decision about the correct reaction had to be taken according to the situation at both lights, so that there were four possibilities i.c. (i) both lights on (ii) both lights off (iii) left on, right off and (iiii) right on, left off. This set-up entailed that inspection of both lights took place before responding and in this way the effect of the display angle would

become apparent. All subjects were tested four times – both in noisy and in quiet surroundings according to a counterbalanced experimental design. The noise had a continually changing intensity and quality. This kind of noise had greatly affected the variability of reaction times in some paper-and-pencil tests (Sanders 1961).

The results indicated that the subjects, who were tested at a display angle of 94°, showed a larger variance of reaction times in noise than in quiet. This effect was not found at the small display angle of 20°. So the increase of display angle had the effect of making the test sensitive to noise. It can be supposed that beyond a certain display angle the subject's strategy has been changed from a simple one – being less sensitive to noise – to a more complex one – that was more sensitive.

The same idea is also present in the work of Jerison (1957) and Jerison and Wing (1957). They found that performance in a simple vigilance task – i.c. Mackworth's clocktest – was not affected by noise but when three clocktests were monitored at the same time, an effect appeared. It is plausible to suppose that the process of shifting inspection had become much more complex in the latter case.

Although the results of all these studies point to the existence of functional changes in performance beyond a certain display angle, the number of experiments is still too small to draw more than very vague conclusions. The generality of the effect is unknown and furthermore nothing can yet be said about which "changes of inspection or search strategy" occur. It may be a sound working hypothesis to connect this rather unspecified expression with the use of the mechanism of peripheral vision and of eye and head movements. So it can be suggested that the reported "change in strategy" between 40° and 80° (Corbin et al. op. cit.) is related to the introduction of head movements to supplement eye movements.

This tentative hypothesis is in line with our earlier suggestion, that changes in the succession of selective acts in the functional visual field might be related with changes in the use of the attention-directing mechanisms (see page 34), although both factors are not necessarily related of course. Is there any evidence from the literature to support the idea of a decreasing efficiency, when eye or head movements become necessary to perform the task? In another experiment of Corbin, Carter, Reese and Volkmann (1958) this question has been posed. In the same experimental set-up as described above, the search method was controlled by varying the instruction concerning the use of eye and head movements during search. The results indicated that optimal performance was reached without any scanning at all, by just fixating the centre of the display field and avoiding eye and head movements. In this way maximal performance was obtained within a certain range, falling off rapidly beyond a critical value. This result is quite natural if one remembers that the "no scanning condition" was nothing but an experiment on peripheral vision. The only difference with the usual threshold measurements was the subject's uncertainty, where to expect the signal.

Using eye and head movements, performance was worse than with peripheral vision, but before accepting Corbin's conclusion that "the best search method is no search at all", we should mention the important fact that, instead of measuring reaction times as in the previous experiment, the signals were presented only for 0.1 sec. and the criterion was whether or not they were detected. It is clear that this set-up strongly favours the peripheral viewing condition. It has been mentioned that the visual threshold for static stimuli is increased during eye movements so that perception during eye movements will be largely prohibited. Now, if a visual angle of 40° has to be covered, the eye movement takes already about 0.1 sec. (Dodge and Cline 1901; Tinker 1942) – that is as long as the presentation time of the signal.

Corbin's results are highly bound to his experimental technique, therefore, and a general conclusion is not allowed. To decide upon the effect of eye- and head movements on visual search a more functional approach is necessary. One possible technique can consist of the prohibition of head movements. In this way we can discover where they are necessary and where not. Another technique is to measure eye and head movements.

So the relation between changes of selective strategy and the occurrence of eye and head movements is still an open question, and furthermore it should be recognized that "changes in selective strategy" as used in this discussion, are not necessarily identical to changes in the amount of information that is processed in a selective act. Both points await further research.

In spite of the uncertainties, the experimental literature has provided at least some starting points. For the moment we will turn especially to the first point, – i.e. the changes in selective strategy and its relation to eye and head movements – leaving aside the relation with the selective process. Then the following questions seem essential.

1. When performance is measured as a function of display angle we

wonder whether changes in selective strategy appear – to be found in the form of a loss in efficiency of performance at certain critical display angles.
2. If this is true, we wonder how far these losses in efficiency are correlated with changes in the use of the attention directing mechanisms (i. c. eye movements, head movements, peripheral viewing).
3. We shall also investigate how far possible losses in efficiency are dependent on the complexity of the task.

2. *Some introductory experiments*

EXPERIMENT 1[1]

METHOD AND PROCEDURE

The task was similar to that, used in the study on noise (see page 37). Only, the lights were replaced by columns of dots, which varied in number. In one condition this number was either two or three, while in another condition it amounted to four of five. The diameter of a dot was 1 cm approx. which was also the distance between two dots.
As in the noise-experiment, two signals were simultaneously presented at equal distances of the subjects meridian and slightly above eyelevel. The subject was seated behind a table on an adjustable chair and at a distance of 70 cm from the screen on which the signals were projected. Reaction was carried out by pressing the correct key. 4 keys were fixed on the table behind which the subject was seated. Again, the decision concerning the correct key to press had to be based on both signals: The possible combinations were four-four (dots per column), four-five, five-four and five-five in one experiment, and two-two, two-three, three-two and three-three in another. In Crossman's terms, the former experiment can be said to have a greater confusion-value (Crossman, 1955). Expressed in this unit, the discrimination between four and five dots has a confusion value of 3.13, while this value amounts to 1.71 at the discrimination of two and three dots (see Crossman op. cit.).
After a reaction, a new stimulus appeared after a timelag of 0.5 sec. The subjects were instructed to start with the inspection of the left signal every time.

[1] The author was assisted in this experiment by Mr. C. L. M. Baerwaldt.

Three experimental variables were introduced:

i. The extent of the horizontal display angle, which was measured at five values i.c. 31°, 49°, 62°, 73° and 86°.

ii. The complexity of the task: the signals could have a confusion value of 1.71 or 3.13.

iii. The freedom to make head movements during the task: in half the conditions head movements were prohibited by fastening the head, while in the other they were allowed freely.

The procedure consisted of two parts. After a training period, lasting five minutes, all subjects performed the task at one constant display angle (19°) and with signals, which contained three or four dots, instead of the numbers mentioned above. This preliminary run lasted five minutes, after which the subjects were randomly assigned to one of twenty experimental groups. In total 80 subjects – conscripted marines – took part. Each experimental group consisted of four subjects. The experimental conditions originated from the combination of the variables. So, each group was only tested at one condition. The experimental session also took five minutes of continuous work.

All reactions were added by a two counters system. One added the total number and the other the number of correct responses. Performance was expressed in terms of the total number of reactions. Errors were neglected in the treatment to avoid speed-accuracy problems. Those subjects, however, who had a higher error percentage than ten percent, were replaced by other ones. Another restriction for participation was that in the preliminary run a minimum of 125 reactions was required. This was done to eliminate the very slow subjects.

Apparatus: A schematic picture of the apparatus is presented in figure 1. The signals were on slides in Leitz-Prado projectors. Normally the lightbeams of the projectors were cut off by shutters that were placed before the projectors. The stimulus selector determined which shutter would be opened and, consequently, which signal would be presented. Each signal had an equal chance of occurrence and the order of successive signals was randomized. A full technical description of this apparatus may be obtained on request from the Institute for Perception RVO-TNO.

The results were treated statistically by means of an analysis of covariance. The performance in the preliminary run was taken as the concomitant variable with respect to performance in the experimental run. The mean difference between the scores at the preliminary task

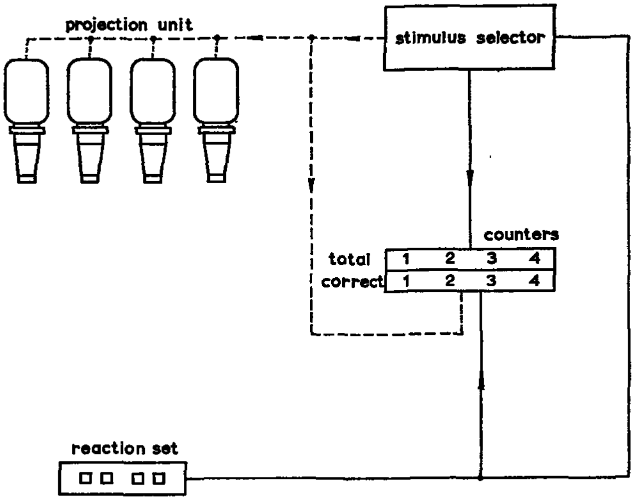


FIG. 1 - Schematic drawing of the apparatus

(x-scores) and those at the experimental task (y-scores) was calculated for each of the three experimental variables, whereupon the y-scores were corrected for the effects of these variables. In this way a y-score was obtained for each subject (y_1-score). To determine the relation between the x- and y_1-scores a product-moment correlation was calculated ($r_{xy1} = 0.94$). In view of this rather high correlation y_{11}-scores could be predicted rather accurately from the x-scores. In the y_{11}-scores we find the bigger part of the individual variation, without the effect of the experimental variables. Hence, by subtracting y_{11}-scores from the original y-scores we can expel the individual variation and retain an estimate of the effect of the variables.

On the y-y_{11}-scores an analysis of variance was carried out. Bartlett's test showed no evidence for a heterogenity of variance, so that no further transformation of the data was required.

RESULTS

The mean (y-y_{11}) scores are presented in table 2 and figure 2.

STATISTICAL ANALYSIS

The analysis of variance showed a significant difference between display angles ($F = 37.75$ $p < 0.001$) and between confusion values ($F = 87.16$ $p < 0.001$). Also the interaction between head condition

TABLE 2 - Mean (y-y_{11}) scores as a function of display angle, confusion value and freedom to make head movements

Display angle	Head free	Head fastened	Head free	Head fastened
31°	+ 24.5	+ 24.5	+ 8.7	+ 0.7
49°	+ 12.5	+ 7.2	+ 2.2	— 2.0
62°	+ 4.5	+ 8.8	+ 0.5	—19.0
73°	+ 5.0	— 4.0	— 6.2	—19.0
86°	— 3.2	— 8.5	—18.0	—41.0
	Confusion value 1.71		Confusion value 3.13	

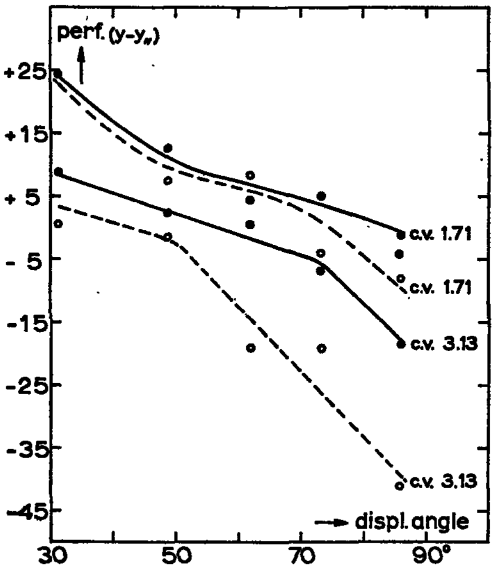


FIG. 2 - Performance as a function of display angle, confusion value (C.V.) and freedom to make headmovements
solid lines (black points): Head free
dotted lines (white points): Head fastened
(covariance score)

and confusion value was significant ($F = 8.79$ $p < 0.01$). Application of t-test showed that a difference of 10.5 reactions between two means was necessary to reach the 1% level of significance. To test whether or not the course of the functions was linear, a regression analysis was carried out on the data obtained at the Head Free condition. The variance ratio obtained for deviation from regression was significant at both functions ($F = 5{,}80$ $p < 0.01$ to confusion value 1.71, and $F = 5.48$ $p < 0{,}01$ to confusion value 3.13).

With this degree of confidence the data cannot be represented by a straight line, which is probably due to the discontinuous course between 31° and 49° (confusion value 1.71) and between 73° and 86° (confusion value 3.13).

DISCUSSION

To summarize the results, a general effect was found of the main variables i.c. display angle and confusion value. An increase in any of these factors was attended by a decrease of performance. The prohibition of head movements had only a significant effect at confusion value 3.13.

As a first comment it can be said that the decrease of performance at the greater confusion value is not surprising in view of the repeated finding that reaction time increases with the difficulty of discrimination (Lemmon 1927; Crossman 1955). More interesting is the finding that the easier signals could be adequately responded to without the use of head movements at a display angle where such was impossible for more complex signals. Here, an analogy is present with the situation, where the subject is required to work with the fixated eye. It is known that the more complex the signal, the smaller the visual angle, where a signal can be adequately recognized with the exclusive use of peripheral vision (Ruediger 1907; Korte 1923). Beyond a certain critical visual angle, eye movements are required to guarantee adequate reaction. So we may discern three levels in the functional visual field in terms of the mechanisms that are used. First the *stationary field*, defined by the extent of the display angle, where a given task can be performed with peripheral vision only. Secondly, the *eyefield*, where the peripheral activity must be supplemented by eye movements. Finally we may enter the *headfield*, if the display angle becomes so large that adequate response is impossible without a further supplement of head movements. The present findings suggest that the transition from stationary field to eyefield, and similary, from eye- to headfield depend on the same kind of variables. This appears to be valid for confusion value, and it is likely that variables as size and brightness will have similar effects.

Further it was expected that a sudden decrease of efficiency might be found at the transition from one to another field, resulting from a – supposed – complication of the inspection strategy. Thus a broken course was predicted, which is confirmed by the results. Inspection of Figure 2 shows that the linear course is interrupted by a sudden drop.

The difficulty arises however, that the drop at confusion value 1.71 and at 3.13 is not found at comparable display angles. In the former condition the drop appears somewhere between 31° and 49°, while in the latter it appears between 73° and 86°. Moreover we should expect two drops in each function, since we assume two transitions, i.e. from the stationary field to the eyefield and from the eyefield to the head-field.

The solution of this problem may be that the range of measurement has been too restricted to cover both drops in each function. According to this idea, another drop should appear at the confusion value 3.13 if performance is measured at smaller display angles. In the same way another drop is expected at the confusion value 1.71 if the display angle is larger than 86°. It is clear that an earlier occurrence of the drop at a more complex signal would be quite in line with the idea that the transition point from one to another level of the functional visual field is dependent on the complexity of the signal.

A new experiment was designed to test this hypothesis.

EXPERIMENT 2

METHOD AND PROCEDURE

The experiment was completely similar to the previous one, except for the variation of the display angle. Measurements of performance in a five minutes workperiod were obtained at 19°, 34°, 52°, 72°, 81°, 94°. The "head fastened" condition was only given at the larger visual angles i.e. 72°, 81° and 94°. Ninety new subjects – air force ratings – were randomly assigned to eighteen groups of five subjects each. They were highly motivated, since they had the impression that the experiment was a part of the officers' examination program.

This in contrast to the previous subjects – conscripted marines – who knew that they were used as experimental subjects. Again, training and a preliminary run on the standard condition took place before the experimental run. In the statistical treatment r_{xy_1} amounted + .90 (σ_x: 8.0; σ_{y_1}: 8.1), delivering a good predictive match for the y_{11}-values.

RESULTS

The mean (y-y_{11}) scores are presented in table 3 and figure 3.

TABLE 3 - Mean ($y-y_{11}$) scores for the various experimental conditions

	Confusion value 1.71		Confusion value 3.13	
Display angle	Head free	Head fastened	Head free	Head fastened
19°	+ 6.0		— 1.0	
34°	+ 5.0		—10.0	
52°	— 4.0		—12.0	
72°	— 7.0	— 6.5	—14.0	—15.0
81°	— 7.0	— 7.2	—15.2	—30.5
94°	—13.0	—24.0	—24.5	—48.0

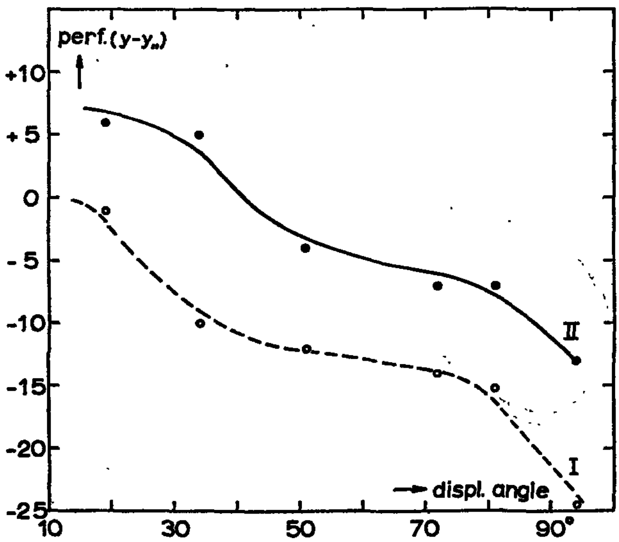


FIG. 3 - Performance as a function of display angle and confusion value I: Confusion value 3.13; II: Confusion value 1.71

STATISTICAL ANALYSIS

Separate analyses of variance were carried out on the data at 19°, 34°, 52° and 72°, 81°, 94° respectively. The former analysis showed a significant difference in performance between display angles ($F = 17.4$; $p < 0.01$) and between confusion values ($F = 48.8$; $p < 0.001$). Also the interaction display angles x confusion values was significant ($F = 4.36$ $p < 0.05$).

In the other analysis of variance - on 71°, 81°, 94° - a significant difference appeared between display angles ($F = 42.5$ $p < 0.001$), confusion values ($F = 88.0$ $p < 0.001$), Head condition ($F = 32.1$ $p < 0.001$) and Display angle x Head condition ($F = 4.10$ $p < 0.05$).

In order to test the linearity of performance as a function of display angle two other two-way analyses of variance were carried out on the Head Free results only. In both cases the deviation from regression was significant ($F = 3.48$ $p < 0.05$ at confusion value 1.71 and $F = 4.02$ $p < 0.02$ at confusion value 3.13).

DISCUSSION

The results confirm the hypothesis that two drops occur when the range of measurement is extended. One drop appears between 20° and 40° – (Drop I) and another between 80° and 95° (Drop II). The actual position of occurrence proves dependent on the complexity of the signal – as was expected.

Another question is whether the drops have a correlative relationship with a transition from one to another level of the functional visual field. We now come to the problem – neglected at the discussion of the first experiment – why drop II did not occur at that display angle, where performance got worse if the head was fastened. Assuming that Drop II (between 80°-95°) reflects the transition from eye- to headfield, we would not expect that prohibition of head movements affects performance before the occurrence of that drop. This is not confirmed by the results however. Especially not at confusion value 3.13, as is clear from fig. 2 and 3, although in experiment 2 the divergence seems to be less than in experiment 1. The subjects could maintain optimal performance with the fastened head considerably longer in the former study. Perhaps the difference between the experimental results is due to motivational factors: the aspirant officers, used in experiment 2, were likely to be more motivated than the conscripted marines of experiment 1, with the result that a larger display angle could be covered without the use of head movements by the former subjects. If this explanation is correct we must assume the existence of an area where head movements are preferred, but not strictly necessary in order to maintain performance. It is possible that the drop only occurs if the upper limit of this area is reached (see Goldstein 1938).

According to this view, we can say that the transition from eyefield to headfield takes place at the display angle where head movements become really necessary. This can explain why Drop II proved to be independent from motivation: both in experiment 1 and 2, the drops are found at similar display angles. The whole idea is illustrated schematically in figure 4.

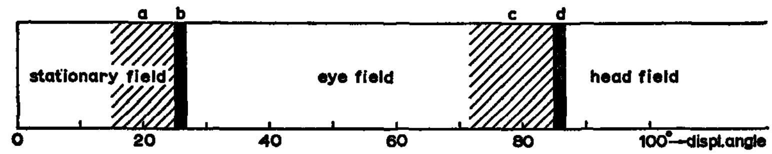


FIG. 4 - Hypothetical scheme of the structure of the functional visual field
a: eye movements preferred; b: eye movements necessary
c: head movements preferred; d: head movements necessary

So the relation between Drop II and the mere occurrence of head movements cannot be maintained, since it is likely that – when allowed freely – head movements are preferred before the display angle, where Drop II appeared. Presumably the same is true for the relation between Drop I and the transition from the stationary field to the eyefield.
Summarizing the results of this section we can say that the hypothesis about changes in selective strategy, when the display angle of the task is widened, is supported by the present experiments. It is also confirmed that the angular areas, where the shifts in strategy occur, is related to the complexity of the task. Finally, it seems that the shifts in strategy are related in some way to transitions from one to another level of the functional visual field.

3. The effect of eye and head movements on performance

In the first place, we shall carry on with the verification of the hypothetical scheme about the relation between the drops and the use of eye and head movements (Fig. 4). At this stage it is difficult to decide whether this relation can lead to an explanation of the drops, or that we deal only with a correlative relationship. If the introduction of eye and head movements causes the drops, we may assume that the loss of efficiency is due to a sudden increase of movement time; at first sight it seems plausible to suppose that with the introduction of a new mechanism in the shift from left to right, the movement time will increase abruptly. In that case the "changes of selective strategy" refer only to a change in the mechanisms involved in the shift from left to right and have no relation with the structure of the selective process as described in Chapter 1.
On the other hand the transition from one to another level of the functional visual field may be related to a change of the selective process – for instance from grouping to successive treatment of signals (see page 34).

The following experiments were designed to shed more light upon these problems.

EXPERIMENT 3

HYPOTHESIS

Highly motivated subjects will be able to maintain performance without the use of eye movements – c.q. head movements – until the display angles, where the drops were found to occur. This hypothesis follows directly from the idea that in a certain angular area eye or head movements are preferred, although they are not necessary (see fig. 4).

METHOD AND PROCEDURE

The task was similar to that used in the previous experiments. Two signals were simultaneously presented at equal distance of the subjects meridian. They consisted of columns of either four or five dots. The decision concerning the correct response had again to be based on both signals. Again reaction took place by pressing the adequate key.
In contrast with the previous experiments, no continuous reaction was asked, but each pair of signals was preceeded by a warning signal, that was presented 3 sec. before presentation at the place where the left signal (S_l) would appear. For each response the reaction time was obtained. As to details of the experimental setting, one is referred to Experiment 1.
The apparatus was modified to fit the requirements of the experiment.
The start of the apparatus by the experimenter was immediately followed by the presentation of the warning signal (W). The 3-seconds interval was achieved by placing a delay unit between the start and the stimulus selector. The original slides in the projection unit, which contained both S_l and S_r on one slide, were replaced by slides, on which only one signal (4 or 5 dots) was printed (see projection unit). To present both S_l and S_r two shutters had to be opened, which was accomplished by placing a relay unit between the stimulus selector and the projection unit. The display angle was varied by shifting the projectors. The advantage of this method is, that measurements at very large display angles could be obtained. This was not possible in the original setting since beyond a certain distance between the signals the brightness of the image decreased, due to their peripheral position on the slides.
The stimulus selector started a timecounter which was stopped at the

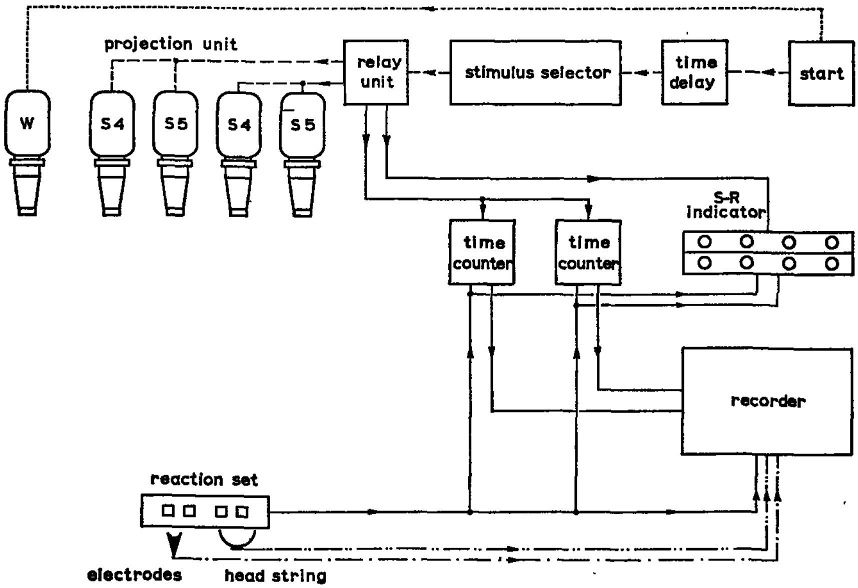


FIG. 5 - Schematic drawing of the apparatus

moment of reaction. Finally the signals – chosen by the stimulus selector – became visible on the stimulus indicator and the same happened with the reactions, enabling an easy control concerning the correctness of the responses. Finally, the headstring, the electrodes and the recorder could be used to measure eye and head movements during the task. This was not done in the present experiment, but especially in the experiments 6-10. Two subjects were highly trained in order to avoid effects of learning during the measurements. Then, they performed series of twenty responses at various display angles, the order being randomly determined. In some runs, the instruction was given to perform the task without eye movements. In these cases S_1 had to be fixated during the responses. In other series, eye movements were required, even if it was felt to be unnecessary. No head movements were allowed throughout the series. The subjects were motivated to reach a maximal performance by informing them that the experiment was carried out to determine the maximal range, where effective reactions could be made by means of peripheral viewing or eye movements. Moreover, the subjects were given knowledge of results after each reaction, which is known to have a motivating effect (Grindley and Elwell 1939, Mackworth 1950, Wilkinson 1958).

From every series of reactions, the median reaction time was obtained. The variation within the series was small enough to forgo statistical tests. The median data are presented in fig. 6.

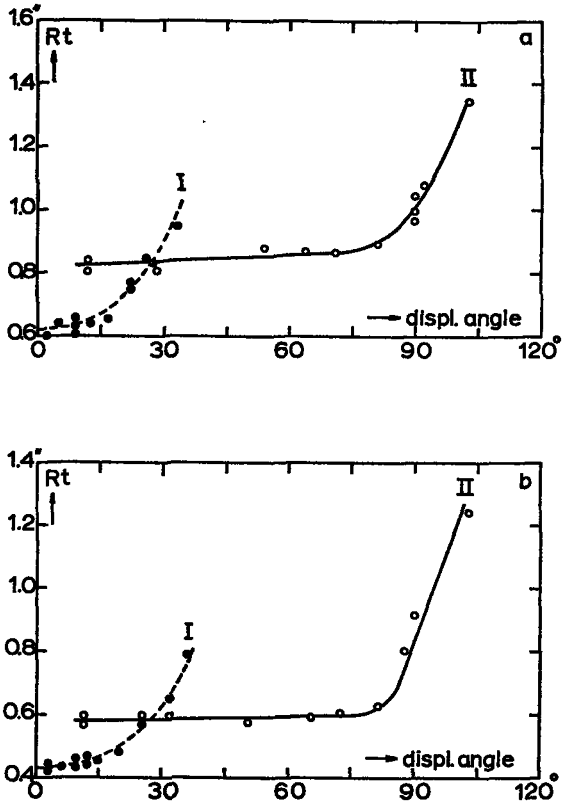


FIG. 6 – Reaction time (in seconds) as a function of display angle
a: subject Th.E; *b*: subject A.F.S.
I: Instruction: eye fixated at left signal; II: Instruction: eyemovements

DISCUSSION

The intersection point between the "peripheral viewing" and the "eye movements" curve coincides remarkably well with the display angle where Drop I occurred. This holds to both subjects. As to the "eye movements" curve a linear course is found until 85°, where upon it rises sharply, indicating that eye movements become insufficient to

maintain performance. This angular distance is also in good accord with that, where Drop II was found.
So the hypothesis is confirmed. Using highly motivated subjects, the transition from the stationary field to the eyefield and, again, from the eyefield to the headfield tallies with the drops. Beyond 25°, eye movements become necessary to perform the task effectively and the same is true for head movements beyond 85°.
It may seem surprising that with the use of peripheral viewing effective performance could be maintained till 25°, in view of the rapid decline of visual acuity in the periphery of the retina. Data from Ruediger (1907) and Woodrow (1938) show that adequate recognition of letters impairs already when given 3°-5° from the fixation point.
To explain this divergence, we can say that the complexity of the signals in the present experiment was much less than in those mentioned. In fact, the subjects reported that the height of the column was taken as an indication for the number of dots. Moreover the total light intensity was more in the case of 5 dots than of 4 dots, which is likely to be another cue. Furthermore, in the quoted experiments, only very short presentation times were used. According to the Bunsen-Roscoe law, presentation time is as important as brightness in order to enable recognition of the signal – until a certain duration anyway (Graham and Margaria 1935). Peripheral recognition is likely to be better therefore if ample inspection time is given and if the signals are easy to discriminate. So, v. d. Geer and Moraal (1962) found that bright and large sized letters, presented for 1½ sec. could be perfectly recognized at an angular distance of 30°. The expectation is, of course, that the stationary field will be much smaller if more difficult signals are employed and it may even disappear if the experimental setting is more complex.
Meanwhile, returning to the main line of the argument, we cannot conclude in a direct way that eye or head movements, which are made before the critical visual angle, are merely a question of preference. To maintain the general hypothesis, it should be shown that the so called preferred eye or head movements have another function than those movements, which are necessarily made. This point is investigated in the following experiments for head movements.

EXPERIMENT 4[1]

METHOD AND PROCEDURE

The task was similar to that used in the previous experiments. The described discrimination task was carried out continually for three minutes. The total number of reactions and errors were collected on counters. Those subjects, who made more errors than ten percent of the total number of reactions, were expelled from the experiment and replaced by other ones. During the experimental sessions, head movements were recorded. For that purpose the subjects' head was placed into a string that was connected with a variable potentiometer. Each movement of the head altered the electrical resistance and these changes were recorded on a graphical writer. The reaction times were recorded on the same track (see fig. 5). The accuracy of the amplitude of the head movements amounted to $\frac{1}{2}°$. The experiment was designed in a Latin Square arrangement, so that each subject performed all possible conditions in a prescribed order. In total 45 subjects – military drivers, aged from 19-21 years – took part in the experiment. They were under the impression that their task was a part of a more general military examination.

The subjects were randomly divided into two groups, one consisting of 21 subjects and another of 24 subjects. Again the experimental variable was the visual angle, formed between the subject and the dotpatterns. The first group was tested at 71°, 81° and 94°, the second at 65°, 80° and 90°. So the Latin squares were of the 3×3 type. Each new Latin square was a replication of the former. Before the experimental runs, the subjects were acquainted with the task by means of instruction and of a short training period. They were asked to work at their highest speed without neglect of accuracy.

RESULTS

The mean number of reactions are represented in table 4 and figure 7. The mean data on head movements in table 5 and figure 7.

STATISTICAL ANALYSIS

On the data of both number of reactions and degree of head movements an analysis of variance was carried out. A square root transformation

[1] The author was assisted in this experiment by Mr. L. F. W. de Klerk.

TABLE 4 - Mean number of reactions at various display angles

Visual angle	Mean number of reactions	Visual angle	Mean number of reactions
71°	72.0	65°	70.5
81°	71.5	80°	71.0
94°	65.0	90°	66.0

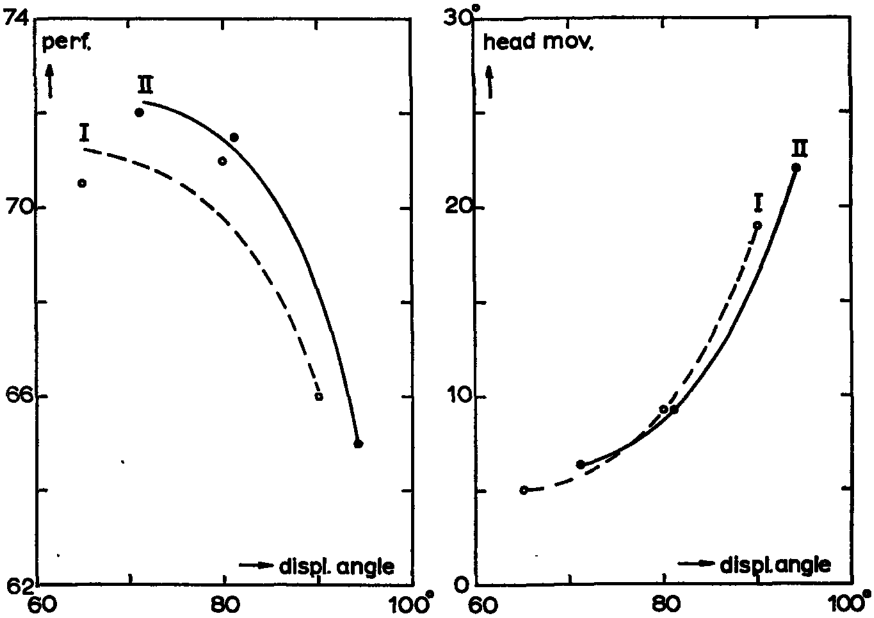


FIG. 7 - Performance (number of reactions) and head movements (degrees) as a function of display angle
I: Results of group II; II: Results of group I

TABLE 5 - Mean degree of headmovements

Visual angle	degree of headmovements	Visual angle	degree of headmovements
71°	6.3°	65°	5.1°
81°	9.2°	80°	9.2°
94°	22.0°	90°	19.0°

was applied to the data on head movements since a correlation between means and variances within groups appeared. In view of the small values, a $\sqrt{x + 0.5}$ transformation was preferred to a $\sqrt{x}$. The statis-

tical analysis showed a significant difference between conditions ($F = 77.8$ and 38.6 resp. $p < 0.001$) and also a significant effect appeared between Trials ($F = 19.1$ and 10.5 $p < 0.01$).
This applies only the number of reactions. As to the degree of head movements a similar statistical procedure showed at both groups a significant difference between conditions ($F = 108.9$ and 69.7 resp. $p < 0.001$). T-tests showed, that for all cases the significant differences between conditions was due to performance between 80° and 90° (or between 81° and 94°). Differences in mean between 65° and 80° (or 71° and 81°) were never significant. Finally a product moment correlation was calculated between the relative increase of the head movements and the relative decrease of performance between 80° and 90°. There was no evidence for such a relationship however ($r = 0.00$).

DISCUSSION

From this experiment the following points seem clear:

1. Drop II reappears between 80° and 90°. Its extent is about 5-6 reactions in a three minutes workperiod, which is in fair agreement with the extent in the previous experiments (about 12 reactions in a five minutes workperiod).
2. Head movements already start to occur at quite a small display angle (a mean of 5° at 65°; see fig. 7). The increase as a function of display angle goes slowly in the beginning but rises sharply between 81° and 90°.
3. From the data in table 5, it can be derived that beyond a display angle of 81° an increase of the display angle is followed by an equal increase of head movement activity. This is illustrated in table 6.

TABLE 6 - The relation between display angle and the percentage of covering by headmovements

Visual angle (A)	degree of headmovement (H)	Δ A	Δ H	Coveringsperc.
65°	5°	15°	4°	27%
80°	9°	10°	10°	100%
90°	19°			
71°	6°	10°	3°	30%
81°	9°	13°	13°	100%
94°	22°			

This result implies that, until the critical display angle of 80°, the bigger part of every increase of display angle, is still covered by eye movements. From 80°, however, the increase is covered completely by head movements.
This reasoning neglects, however, that a head movement of one degree covers more than an equivalent eye movement, due to the fact that the axis of the head lies behind that of the eye.
A second point concerns the tacit assumption that eye and head movements are additive in covering a certain visual angle. This is not true however; for instance, Woodworth and Schlosberg (1954) remark: "If one looks suddenly to the right, as in localising a click, the eyes lead in a quick saccadic movement. The heavier and slower head follows and eventually the trunk may turn too. The eyes get the object first and fixate it with a compensatory backward movement, while the heavier head continues his turn".
This means that, when eye and head work together, the sum of their amplitudes – measured separately – will be more than the display angle, which is covered. The surplus is corrected by a compensatory eye movement. Small head movements, therefore, may have no effect at all on the amplitude of the saccadic eye movement and may merely bring away the compensatory eye movement. According to this view, such head movements are unnecessary, strictly spoken, although they are preferred functionally.
For the present experiment this means that up till 80° the eye movements are likely to cover the full angular distance. Beyond 80° this picture will change. From this display angle head movements take over a part of the job and they start to play an independent role in the shift from S_l to S_r. According to this description, head movements, occurring before the critical display angle of Drop II, are likely to have an other functional meaning than those occurring beyond that display angle. The former are thought to be auxiliary, while the latter are necessary.
A final test of this hypothesis can be provided by the analysis of the interplay of eye and head movements. This will be considered in experiment 6. We will turn first to a further check of the relation between Drop II and the transition from eye to head field by testing the deduction that Drop II occurs at a smaller display angle, if the subject's field of vision is restricted – as in monocular vision. It is likely that head movements are needed earlier at this condition, and consequently, it will give rise to a proportionally earlier occurrence of Drop II.

EXPERIMENT 5

METHOD AND PROCEDURE

The task, the experimental design and the instruction of this experiment were equal to that of experiment 4. Twenty-four new military drivers served as subjects and they performed the task with monocular vision. This was done by covering the subject's left eye. The subjects were tested at three different display angles (57.5°, 71° and 81°).

RESULTS

The mean number of reactions and the mean degree of head movements are presented in table 7 and figure 8.

TABLE 7 - Mean number of reactions and degree of headmovements (Monocular vision)

Visual angle	Mean number of reactions	Mean degree of headmovements
57.5°	70.5	2.5°
71.0°	69,5	4.6°
81.0°	65.0	12.7°

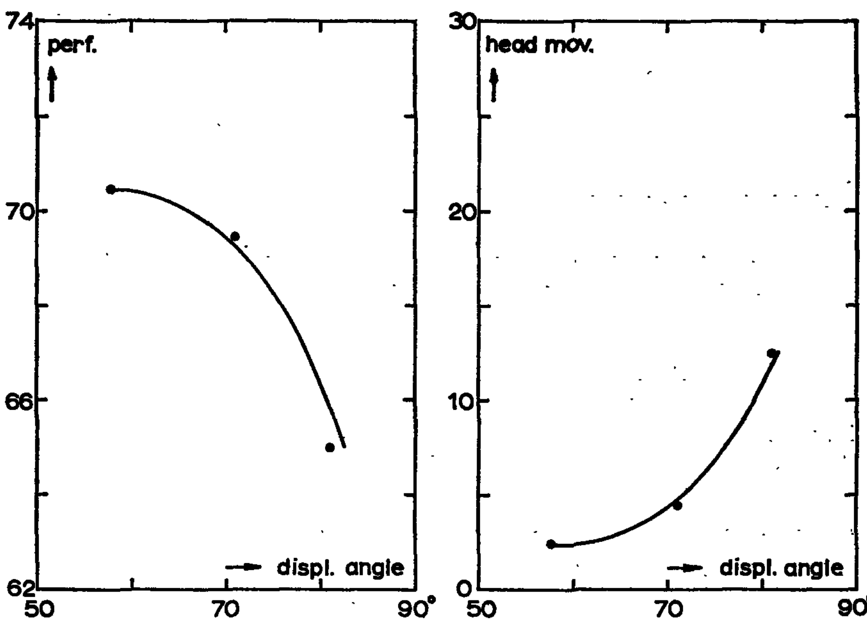


FIG. 8 - Performance (number of reactions) and head movements (degrees) as a function of display angle under condition of monocular vision

The usual statistical analysis showed a significant difference between both number of reactions and degree of head movements at the 1% level ($F = 46.1$ at number of reactions and $F = 37.2$ at head movements).
As appears from the data, the drop occurs earlier when the task is performed with monocular vision (at 70° instead of 80°). The increase of head movements also occurred at 70°. So both phenomena kept running parallel.
A direct comparison of binocular and monocular data is only possible within this experimental design, if the same subjects have performed both the binocular and monocular condition. The experiment was supplemented in this way.

EXPERIMENT 5a

METHOD AND PROCEDURE

Using an equal experimental design and task, new subjects did two experimental series at the same display angle. One with binocular and another with monocular vision.
36 subjects were divided randomly into three groups of twelve. Group one was tested at a display angle of 71°, the other groups at 81° and 94° respectively. Both head movements and number of reactions were measured.

RESULTS

The mean data are shown in table 8 and figure 9.

TABLE 8 - Mean data on performance and degree of headmovements. Only data in the vertical direction can be compared, since in the horizontal direction different groups of subjects are used

	Mean number of reactions			Mean degree of headmovements		
	71°	81°	94°	71°	81°	94°
Binocular	67.4	71.0	66.1	3.0°	7.0°	19.5°
Monocular	68.3	66.5	65.0	2.5°	14.4°	28.0°

As to performance the statistical analysis showed a significant difference between viewing conditions at an angular distance of 81° ($F = 40.4, p < 0.001$). Head movements occurred with a larger amplitude at the monocular condition at 81° and 94° ($F = 6.07, p < 0.05$) and ($F = 12.2, p < 0.01$).

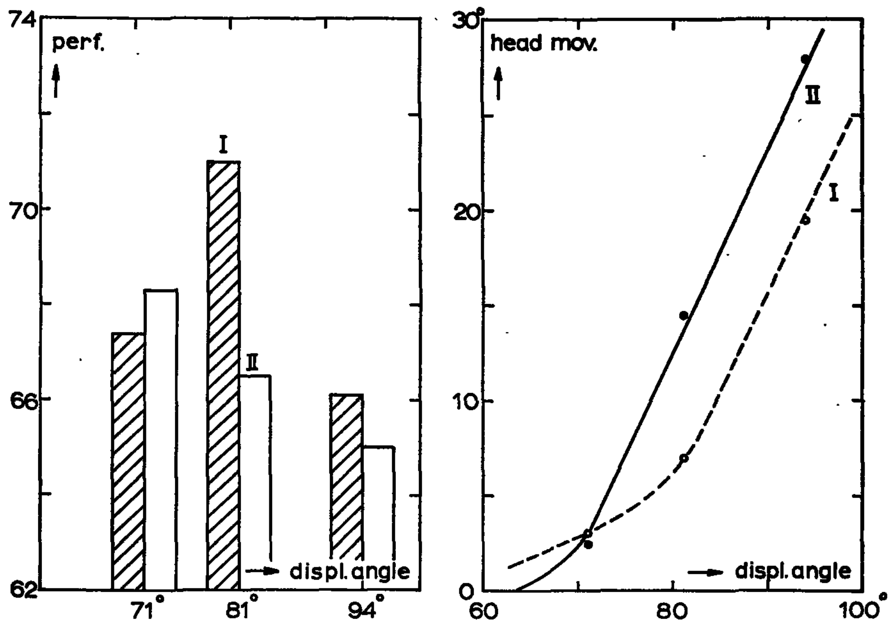


FIG. 9 - Performance (number of reactions) and head movements (degrees) as a function of display angle
I: Binocular vision; II: Monocular vision

DISCUSSION

The results confirm the hypothesis that the display angle, where Drop II appears, depends on the extent of the display field which the subject has at his disposal.

Thus the experiments, reported so far, form a fairly homogeneous picture. They confirm the hypothesis of the relation between Drop II and the transition from the eye field to the headfield. A weakness is that no conclusive evidence has yet been brought forward about the meaning of head movements before and beyond Drop II. The present experiments have provided, however, a fairly detailed hypothesis, that will be investigated in the following experiment. Apart from this aim, the hypothesis concerning the relation between Drop I and the occurrence of eye movements will be considered also.

EXPERIMENT 6

METHOD AND PROCEDURE

The above mentioned aims require, in fact, a repetition of the previous

experiments with simultaneous measurement of eye and head movements. The technique of measuring eye movements has strongly developed since the early work of Dodge (1905): An extensive historical survey is provided by Carmichael and Dearborn (1948), who stress mainly two methods, i.c. electro-oculography and corneal reflection. The latter method had been recently refined by Mackworth and Mackworth (1958), using the television eye marker and the method is also frequently used in measuring fixation shifts during reading (Johannson and Backlund 1960). For our purpose it has the disadvantage however, that head movements easily disturb the record. Mackworth and Mackworth (1958) state for instance: "The importance of head fixation is seen in the fact that the required minimum registrable eye movement of one degree of arc could easily be confused with an artefact from a head movement; such artefacts can arise from head movements as small as 0.075 mm".
So the electro-oculographical technique was preferred since by this means eye and head movements can be recorded independently. The main difficulties of the latter method concern the easy occurrence of drift, which obscures the correct place of the eye fixation on the graphical record. Moreover the accuracy of the amplitude is less than with the corneal reflection method. Neither disadvantage seemed decisive, however. Using adequate electrodes, the drift component can be reduced considerably (White and Ford 1959; Michon and Kirk 1962), and the remaining slow fall may be corrected by regular recalibration. As to the accuracy, we can regard one degree of arc as amply sufficient, when large eyeshifts are measured. This can be easily obtained with electro-oculography (Shackel 1958). Finally the method is known to offer fewer difficulties if only horizontal eye movements are recorded, as is the case at the present problem.
Two platina electrodes were fitted on to the subject's temples at eye-level. To improve the conduction both the electrodes and the skin were smeared with moist shaving cream. A third electrode was fitted on the forehead and served as "earth". The electrodes were bound closely to the skin by means of a string. The potential difference, resulting from the eye movements, were amplified and recorded on a multichannel graphical writer. The head movements were measured in the way described earlier (see page 53) and recorded on another track of the same graphical writer, so that a simultaneous record of eye and head movements was obtained (see fig. 5).
The same task was used as in experiment 3. So no continuous reaction

took place, but each signal was preceeded by a warning stimulus that was given 3 sec. before the signal arrived. After the reaction, based upon S_l and S_r, there was a break until the warning signal was presented anew. The latter was presented at the same spot as S_l. The signal-response process and the eye and head movements were recorded and reaction times were measured. The onset of the signal and the moment of pressing the key were also recorded on the graphical writer, which enabled the calculation of the inspection time before the movements were made. The accuracy of the time measurements was 0.01 sec. approx. and of the movements about one degree.
Six subjects were tested at angular distances of 12°, 24°, 47°, 77°, 99° and finally the reaction time to S_l, when presented alone, was measured. For each condition 20 reactions were obtained; the order of the conditions was according to a Latin Square arrangement. Six other subjects were tested in the same way at display angles of 6°, 18°, 36°, 66°, 77° and 99°. Before the experimental series, the subjects got two training series in all possible conditions to exclude great learning effects during the experimental series. They were instructed to react both rapidly and accurately.

RESULTS

1. The mean amplitudes of eye and head movements are presented in tabel 9 and figure 10.

TABLE 9 - Mean amplitude of eye and head movements as a function of display angle

Group I			Group II		
display angle	eye novements	head novements	display angle	eye novements	head novements
12°	12°	–	6°	3°	–
24°	24°	–	18°	15°	–
47°	48°	1°	36°	39°	–
77°	74°	10°	66°	68°	9°
99°	85°	30°	77°	78°	12°
			99°	80°	42°

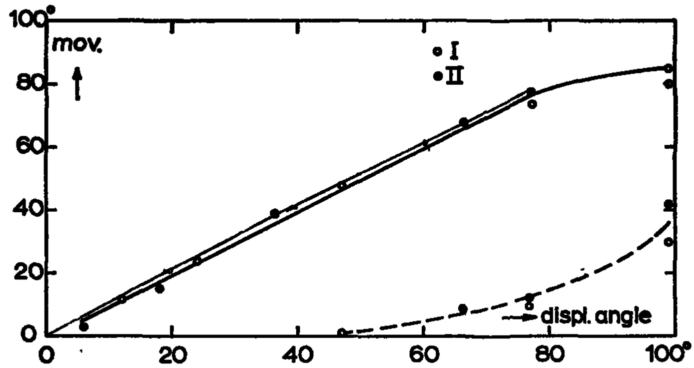


FIG. 10 - Eye and head movements as a function of display angle
I: group I; II; group II
solid line: eye movements; dotted line: head movements

DISCUSSION

The hypothesis that at display angles smaller than 80°, head movements play a subordinate role, is also confirmed by the present results. It is clear from table 9 that until 77° the whole display angle is covered by the saccadic eye movement. Beyond 77° this curve flattens rapidly and head movements increase considerably, becoming a lengthening-piece of the eye movement. The functional meaning of head movements before Drop II may be merely to lessen the muscular stress, that is evoked if the eye is required to take position at a marginal point of the eyeball. After a compensatory movement this position becomes less extreme.

It is plausible that highly motivated subjects endure greater stress in this respect and are able therefore to keep up performance till a larger display angle – if the head is fastened.

Evidence that the saccadic shift of the eye is followed by a compensatory backward movement – when head movements are made – was obtained in all records. If no head movements were present, the compensatory eye-shift also disappeared. Some examples of the records – representative for most measurements – are given in figure 11.

It can be seen that eye and head movements start moving almost simultaneously – only in some case the eye starts slightly earlier. The eye arrives first at S_r, while the sway of the head continues, which tallies with the description of Woodworth and Schlosberg (1954). Drawing a straight line through that part of the head movement, where the velo-

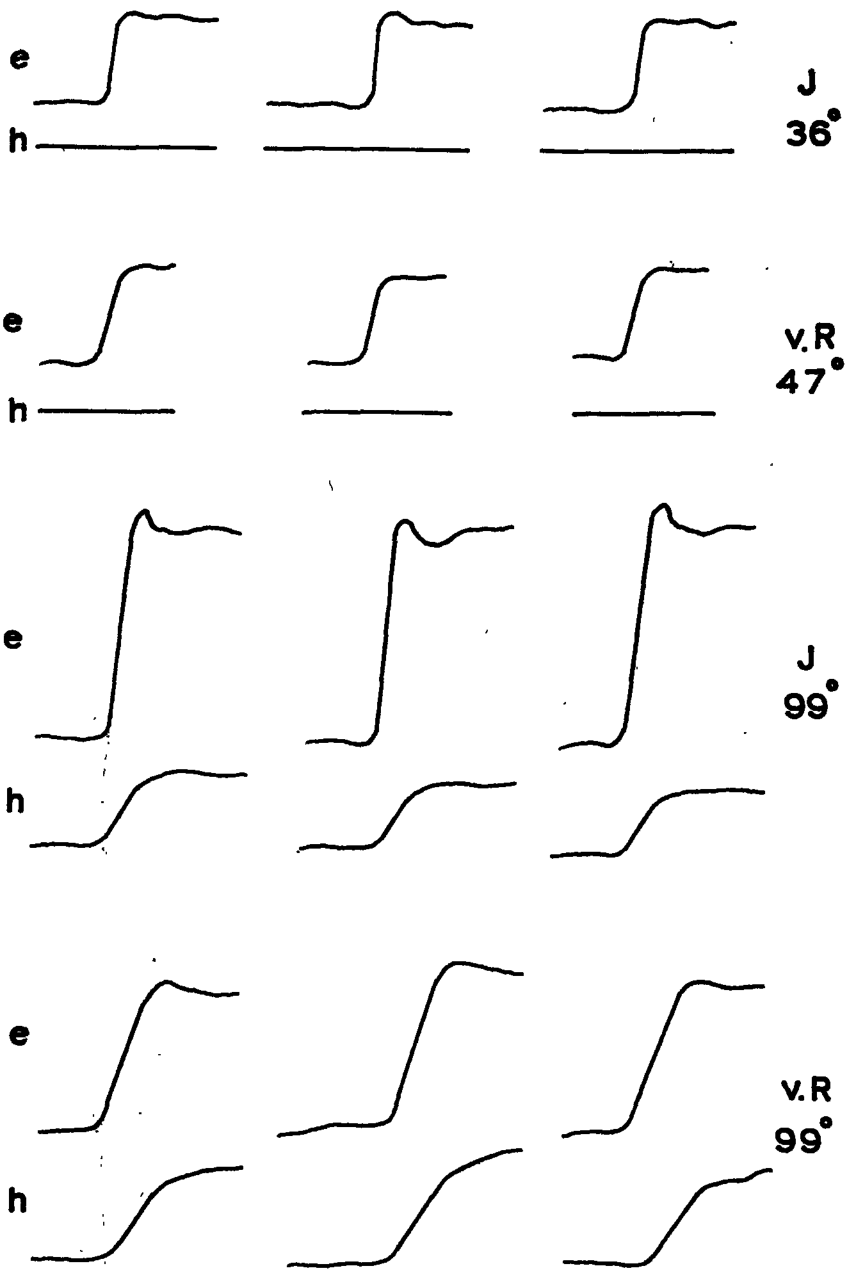


FIG. 11 - Some records of eye and head movements
e: eye movement; h: head movement

city is constant – i.c. the straight parts in the records – it can be seen that the lines diverge when the eye movement has reached its maximum. So, when the eye arrives at S_r, the decelaration of the head starts. During the latter period the compensatory eye movement takes place.

The data of table 9 are also relevant for the relation between Drop I and the transition from the stationary field to the eyefield. After the discussion on head movements, which occur before they are strictly needed, it will be scarcely surprising that eye movements also occur before the display angle where Drop I was found, and they even cover the full angular distance except at the smallest display angle. In accordance with the foregoing account on head movements, we may explain this finding again as a question of preferred behaviour. This was indicated already by the results of experiment 3, where it was shown that the subjects are able of reaching efficient performance with the mere use of peripheral vision up till about 25°.

In order to validate this hypothesis it should be demonstrated that S_r has been already discriminated, before the eye movement is actually made. The shift from left to right should be at best a kind of preferred check, made during the response. For that reason, we will turn now to an analysis of the reaction times of experiment 6. The total reaction times were split up into three parts: (i) inspection time of S_l (T_l); (ii) the movement time of the eye (m), and finally (iii) the inspection of S_r followed by the reaction (T_r). The data are presented in table 10 and fig. 12 and 13.

TABLE 10 - Inspection- movement- and decision time as a function of display angle

display angle	T_l	m	T_r	$T_l + T_r$
12°	.44	.04	.38	.82
24°	.42	.06	.44	.86
47°	.43	.11	.51	.94
77°	.43	.18	.54	.97
99°	.47	.22	.60	1.07
Rt-S_l:	.55			.55
6°	.37	.01	.32	.69
18°	.37	.05	.34	.71
36°	.37	.09	.39	.76
66°	.36	.17	.42	.78
77°	.36	.20	.43	.79
99°	.41	.24	.49	.90

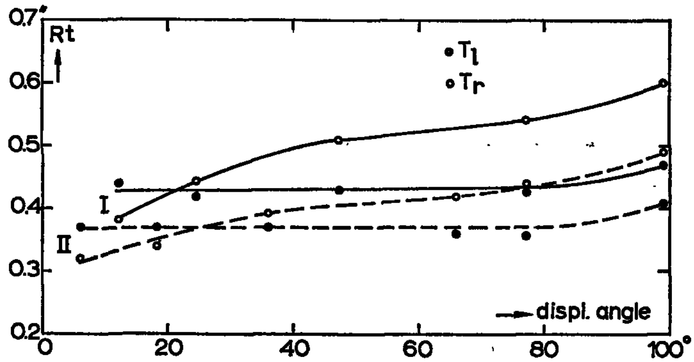


FIG. 12 - Reaction time as a function of display angle
T_l: Inspection time of S_l; T_r: Inspection of S_r plus reaction
I: Group I; II: group II

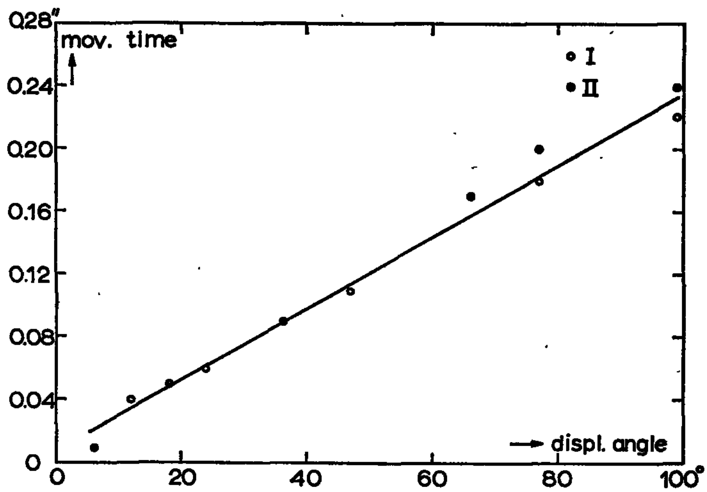


FIG. 13 - Movement time as a function of display angle
I: group I; II: group II

STATISTICAL ANALYSIS

Analysis of variance was carried out on the inspection time of S_l, S_r, on the sum of both (= total reaction time without movement time) and on movement time. Except at movement time, significant differences were found between subjects. The significance between display angles for the various analyses is summarised in table 11.

TABLE 11 - Summary of the significant differences between display angles

		Group I	
T_l (and Rt-S_l):	$F = 5.3$	$p < 0.01$	M_1-$M_2 = 0.06$
T_r:	$F = 10.87$	$p < 0.001$	M_1-$M_2 = 0.06$
$T_l + T_r$:	$F = 32.82$	$p < 0.001$	M_1-$M_2 = 0.08$
		Group II	
T_l:	$F = 1.20$	$p > 0.05$	
T_r:	$F = 18.95$	$p < 0.001$	M_1-$M_2 = 0.05$
$T_l + T_r$:	$F = 34.79$	$p < 0.001$	M_1-$M_2 = 0.06$

At the analysis of movement times there was also a highly significant difference between display angles ($F = 56.50$ $p < 0.001$). The deviation from linear regression was negligible, so that the increase of movement time as a function of display angle can be safely represented by a straight line. The linearity of regression was also tested for the "$T_l + T_r$", delivering a significant "Deviation of regression" on the 5% level ($F = 3.09$). Inspection of the 5% limits (see table 11 and fig. 12) shows that this is mainly due to the discontinuity between 18° and 36° and between 77° and 99°. The same differences are significant at T_r, but not at T_l. In the latter case an approximately horizontal line appears, with a slight upward tendency at 99°. As this increase occurs both at group I and group II, it might become statistically significant if a larger group of subjects is used. Finally, t-tests were applied to decide upon the differences between T_r and T_l within display angles.

99° (Group I + II combined): $t = 3.25$ $p < 0.01$ $Tr > T_l$
77° (idem): $t = 2.94$ $p < 0.02$ idem
36°, 47°, 66° (combined) : $t = 2.47$ $p < 0.05$ idem
6°, 12°, 18° (combined) : $t = 1.66$ $p < 0.2$ $T_r = T_l$
At 6°, T_l tended to be larger than T_r ($t = 2.09$ $p < 0.1$).

DISCUSSION

Supposing that during T_l only information about S_l is obtained, **we** expect that T_r takes considerably more time than T_l, since T_r covers both the inspection of S_r, the decision and the motorreaction. This is confirmed for the values in the eye- and headfield, though the level of significance is less as the display angle gets smaller. It is not confirmed for the values, obtained at angles smaller than 25°; here T_l equals T_r,

while there is even a tendency towards $T_l > T_r$ at the display angle of 6°.
So there is some evidence that, in the stationary field, information about S_r is obtained before this signal is actually reached by the eye. This may happen either during T_l – which was in fact our hypothesis – or during the eye movement or during both actions. The acquisition of information during the eye movement is rather improbable however, in view of the literature (Holt 1903, Dodge 1905, Latour 1962). Moreover we would then expect a reduction of T_r also at the larger display angles. The first mentioned hypothesis seems most adequate therefore. So the idea is supported that in fact eye movements are not necessary to discriminate S_r as long as the display angle does not exceed the stationary field.
In conclusion it can be said that the experiments of this section support the conception of structure in the functional visual field. The drops in performance – as found in exp. 1 and 2 – have reappeared and strong evidence is present for a relation between the drops and the introduction of eye and head movements.
As to the background of the drops we have put forward the hypothesis that jumps in movement time needed to shift from S_l to S_r may occur at the introduction of eye and head movements (see page 48). This hypothesis has to be rejected however, since movement time and display angle show a beautiful linear relationship (see fig. 13). This has been found already for eye movements only (Dodge and Cline (1901), Tinker (1942), White, Eason and Bartlett (1962); the present results indicate that movement time is unaffected when head movements supplement the eye activity.
Thus, after subtraction of the movement time, the drops in reaction time are still present (see fig. 12). The further subdivision in "inspection time to S_l" and "inspection time of S_r plus reaction" shows that the bigger part of the drops is due to the course of the latter time. This forms a basis to the second attempt to explain the drops, which started from the assumption that the drops are due to changes in the selective process (see page 48). We can assume that in the stationary field both S_l and S_r are taken in the same selective act – they are grouped – enabling a more rapid transmission than would be possible, if two successive selective acts were required. The latter process may occur in the eyefield and in this way Drop I might be explicable.
An objection to this theory is that in this way the occurrence of Drop II becomes mysterious and therefore the reasoning must be regarded at

best as incomplete. Perhaps it can be suggested that the perceptual intake is no matter of a dichotomy: "both signals in one selective act" or "one in an act", but that an intermediary stage is possible. Following this assumption, only in the headfield would two successive selective acts be required; the stationary field would be covered by one selective act, while in the eyefield the intermediary process would occur. It is clear however, that this explanation is highly speculative and needs further experimental tests. This will be undertaken in the next chapter.

CHAPTER 3

THE PHENOMENON OF GROUPING

So the question to be dealt with in this chapter concerns how far it is justified to explain the drops in terms of grouping and successive handling of signals. Before turning to experiments we shall recapitulate for a moment what to expect in both cases. Although the terms have been met in chapter 1, such a summary can be useful in order to arrive at specific experimental hypotheses.

1. Successive responses to simultaneous signals

As mentioned before, grouping is said to occur if more than one signal is transmitted in one and the same selective act. Thus in the case of two simultaneously presented signals (S_l and S_r), the process can be described by

$$\text{Discrimination } (S_l + S_r) \rightarrow \text{response } S_l \rightarrow \text{response } S_r \quad (1)$$

This implies that Rt_l will be larger than Rt_r – if we measure Rt_r from the moment that the reaction to S_l was completed. The discrimination of S_r is made together with that of S_l, so that after response S_l only a motorreaction is left.

When, however, two selective acts are needed – one for S_l and another for S_r – we arrive at the following expression:

$$\text{Discrimination } S_l \rightarrow \text{response } S_l \rightarrow \text{Discrimination } S_r \rightarrow \text{response } S_r \quad (2a).$$

which implies that Rt_l equals Rt_r – under the assumption that Rt_l equals Rt_r if the signals are given on their own.

This is not the necessary action in successive handling, however, since the subject may prefer to collect the perceptual data before giving any response. In that case the process goes as follows:

$$\text{Discrimination } S_l \rightarrow \text{storing } S_l \rightarrow \text{Discrimination } S_r \rightarrow \text{response } S_l \rightarrow \text{response } S_r \quad (2b)$$

in which case Rt_l will again be larger than Rt_r.

How to differentiate between grouping and successive handling, if the latter procedure is applied? This is difficult to determine by means of reaction times, since in both cases Rt_l will be larger than Rt_r.
A way out of this problem can be by considering the relative efficiency with which the actions are carried out. We have discussed already that grouping is supposed to be more efficient than successive handling. If both S_l and S_r contain one bit of information, we have one "chunk" in which two bits are transmitted as opposed to two successive chunks in which one bit is processed. It has been mentioned before that reaction time does not increase evenly with the amount of information – see page 22, – so that grouping will be the more efficient process. This reasoning forms the basis for the explanation of the drops in performance, which were found in the previous chapter. Now, if we want to decide whether grouping or successive handling occurs in a certain experimental situation, the experiment can be carried out with the instruction to group the signals and it should be repeated with the instruction to handle the signals successively – according to process 2a. Now if in the former experiment grouping actually takes place, we expect that the total reaction time – i.c. from the arrival of the signals till the completion to Rt_r – will be shorter than in the latter experiment. If in the former experiment successive treatment according to process 2b occurs, we do not predict such a difference in efficiency.
This reasoning is not quite watertight, since it starts from the assumption that successive treatment according to formula 2a and 2b are equally efficient, which is not necessarily true. It can be held that 2a will be the more rapid process, since no storing process is involved and since during the motor reaction to Rt_l, the second selective act can already start (Poulton 1956, Davis 1957). On the other hand, 2b may be faster since the transmission of S_l may continue during the eyeshift to S_r. It seems clear, anyway, that the difference in reaction time between grouping and successive treatment (according to formula 2a) should be much more striking than a possible difference between process 2a and 2b.
Questions around grouping and successive handling have already been urgent in the literature, especially in the work on the so-called psychological refractory period. This line of research has been touched briefly in chapter 1 – page 20 – and it is concerned with the way in which successively presented signals are assimilated. To what extent grouping and successive handling occur in that context is still unsatisfactory settled, and we will return more extensively to that point later

on (paragraph 4). Only this: In the experiments on the psychological refractory period the selective process is studied in the case of successively presented signals, while in the present experiment the signals always arrive simultaneously. On the other hand, the spatial factor is kept constant in the former research, while it is varied in the latter investigations. In a way the research lines are supplementary therefore.
The first question to be answered is whether or not phenomena of grouping can be detected. There is already some evidence from experiment 6 where it was concluded that S_r was largely discriminated during fixation of S_l, if the signals were given within the stationary field. This conclusion could not be elaborated because the processes during the fixation of S_l and S_r were not equivalent. When we wish to compare both parts of the reaction, this should be avoided. Therefore more evidence about the degree of grouping or successive treatment may be obtained by asking separate reactions to S_l and S_r, instead of one reaction to the combination of both. This was done in experiment 7.

EXPERIMENT 7

METHOD AND PROCEDURE

The task was similar to that used in the previous experiments. Two signals were exposed simultaneously at equal distance of the subjects' meridian. They consisted of bright columns of dots on a dark background and they contained either four or five items with equal chance of occurrence. Separate reactions had to be given to S_l and S_r, by pressing successively two adequate keys. The pattern of keys was equal to that used previously. Three seconds before the arrival of a pair of signals, a warning signal was presented. Two reaction times were obtained (Rt_l and Rt_r) and eye- and head movements were recorded.
Further details about the experimental setting were equal to those of experiment 6. The only modification of the apparatus was that a second timecounter was introduced to measure Rt_r apart from Rt_l. Six subjects – naval ratings – took part in the experiment. They were tested under five different display angles – i.c. 12°, 24°, 47°, 77°, and 99° and also subjected to an experimental session, where only the choice reaction time to S_l was obtained (Rt_0). In each session, twenty correct responses were obtained; the order of the sessions was varied in a Latin Square arrangement. Before the experiment started, the subjects received ample training on all experimental conditions.
The instruction was given to finish Rt_l before shifting the eye to S_r,

which was continuously emphasized during training. This instruction is important, since it is the aim of the experiment to decide whether or not S_r is transmitted together with S_l. If the subjects prefer to shift to S_r before reacting to S_l, it is difficult to decide in this context whether the signals have been grouped (formula 1) or handled separately (formula 2b).

RESULTS

It was found, in general, that the latter instruction was difficult to obey at most of the display angles. Two subjects proved to be unable to follow the instruction at all and for this reason they were replaced by others. With respect to the reactions, those which were not "in time" – referring to the requirement that the eye was shifted to S_r after S_l was reacted to – were expelled from experimental treatment. Each session was continued until 20 "correct responses" had been obtained. First we will present the percentage of reactions that was discarded, together with the mean difference between the moment of reaction and the start of the eyeshift.

TABLE 12 - Percentage of Rt_l "not in time" as a function of display angle, and the mean time of the "delay"

Display angle	Percentage Rt_l, not in time	Mean delay of Rt_l (sec.)
12°	48,5	.12
24°	41.6	.10
47°	32,2	.09
77°	38.0	.10
99°	8.6	.06

As to the "Rt_l in time," the median values of Rt_l and Rt_r were obtained. It was assumed that Rt_r could start at the moment that the eyeshift had reached its minimum value (see fig. 14).

The mean data on Rt_l, m and Rt_r are presented in table 13 and fig. 15.

STATISTICAL TREATMENT

Analysis of variance was carried out on the data of table 12 and 13, which produced the following results:

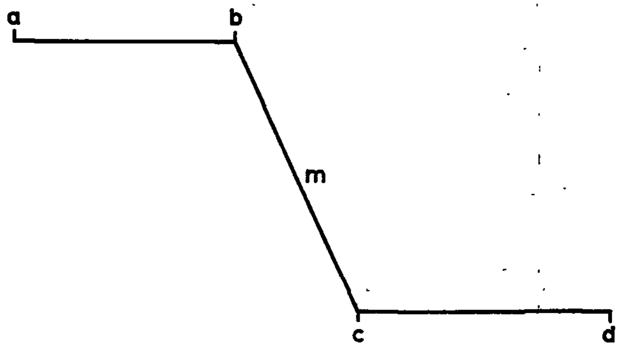


FIG. 14 - The measurement of Rt_l and Rt_r

a: arrival of the signals c: Assumed start of Rt_r
b: Reaction to S_l d: Reaction to S_r
m: movement from S_l to S_r

TABLE 13 - Mean reaction time as a function of display angle

Display angle	Rt_l	m	Rt_r		Total without movementtime
12°	.63	0.04	.37		1.00
24°	.61	0.06	.34		.95
47°	.56	0.11	.36		.92
77°	.56	0.16	.40		.96
99°	.54	0,22	.50		1.04
Response to S_l only (Rt_0)	.53		.53	$2 \times Rt_0$	1.06

Table 12:
Between percentage of discarded responses: $F = 24.8$ ($p < 0.001$)
Between delay of Rt_l: $F = 30.1$ ($p < 0.001$)
Application of t-test showed that the significance was mainly due to changes in performance at 99°.

Table 13:
Between Rt_l : $F = 2.47$ ($0.1 > p > 0.05$); M_1-M_2: 0.07 $p < 0.05$ (t-test)
Between Rt_r : $F = 10.06$ $p < 0.01$); M_1-M_2: 0.06 $p < 0.05$ (t-test)
Between ($Rt_l + Rt_r$): $F = 2.37$ ($0.1 > p > 0.05$); M_1-M_2: 0.11 $p < 0.05$ (t-test)

Between Rt_l and Rt_r – within conditions, – t-tests were calculated; the mean difference proved to be significant at 1% level at all display angles, except at 99° ($p > 0.1$).

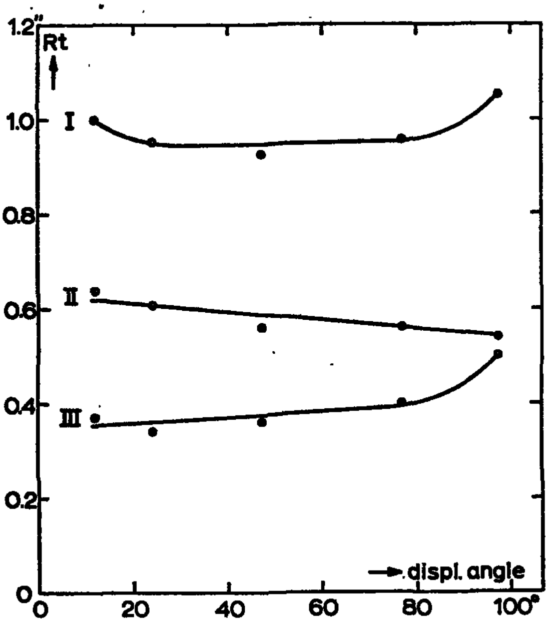


FIG. 15 - Reaction time as a function of display angle
I: $Rt_l + Rt_r$; II: Rt_l; III: Rt_r

DISCUSSION

The most striking result of this experiment is the fact that most subjects had great difficulty in not shifting the eye to S_r before Rt_l had finished. This occurred at all display angles except at 99°, where most subjects were able, after some training, to obey the instruction quite well. Apparently the most effective way of behaviour in this experimental situation was to shift the eye before the response to S_l had finished.

We may put forward two possible explanations for this phenomenon: First, we can assume that after transmission of S_l, the eyeshift and the motorresponse can co-exist. It has been shown that new information can enter during the efferent response time and, thus, it would not be unlogical that the motorresponse and the eyeshift can be carried out simultaneously – without retarding Rt_l (see Poulton 1956). This addition seems essential for this theory: the Rt_l, made "in time", should not differ from that, made during or after the eyeshift to S_r, if the effect is solely due to a co-existence of response and eyeshift. For each condition, therefore, the mean "Rt_l in time" was compared with

TABLE 14 - Mean difference between Rt_l (not in time) and Rt_l (in time). No difference could be obtained at 99°, since there was a lack of Rt_l (not in time), under that condition. Applicance of t test to the combined differences showed a highly significant effect ($t = 4.40 \quad p < 0.01$)

Display angle	[Rt_l (not in time) – Rt_l (in time)]: number of subjects
12°	+ 0.07
24°	+ 0.09
47°	+ 0.08
77°	+ 0.06

that "not in time." The results of this treatment are found in table 14. So in general Rt_l (not in time) is larger than Rt_l (in time), pointing to a tendency to retard the reaction to S_l in favour of inspection of S_r, rather than to a simultaneous motorresponse and eyeshift. It cannot be said, however, that the latter process plays no role at all, but only that it is not the main determinant of the tendency to leave S_l before the response takes place.

Consequently the subjects seem to prefer to collect the perceptual data before giving any response, which phenomenon is in full accordance with grouping. Successive handling, according to formula 2b, seems less likely, since it is difficult to see why it proved virtually impossible to obey the instruction in that case. It is assumed that inference of a response is quite possible in successive handling. Both in the stationary field and the eyefield, the grouping effect is present, which is in contrast to our preliminary hypothesis that grouping is restricted to the stationary field.

The effect disappears at a display angle of 99°, which suggests that in the headfield the role of grouping has finished.

Evidence for grouping in the stationary field and the eyefield can be obtained also from those reactions at which the instruction was obeyed. It appears from table 13 that Rt_r was smaller than Rt_l in all cases but 99°, which agrees with the results of experiment 6, and which stresses again that information about S_r must have been obtained before the eye arrived at S_r. In the headfield, however, the prediction of the successive treatment process fits, namely $Rt_l = Rt_r = Rt_o$.

A curious result is, however, that in spite of the evidence for grouping, the drops in performance have partly disappeared. This is most obvious for Drop I. Instead of a decrease of reaction time in the stationary field, there is rather an increase (see fig. 15). By virtue of experiment 6, we should find Drop I mainly in an increased Rt_r, while Rt_l should remained nearly constant. In the present results the increase of Rt_r is absent, while Rt_l even tends to decrease. Drop II should be also found largely in an increase of Rt_r, which is confirmed, though the drop is blurred by a slight decrease of Rt_l.

These results are conceivable however, when it is recognized that the instruction has suppressed the natural way of responding in both the stationary field and the eyefield. The charge that the subjects should complete Rt_l before moving the eye to S_r may have easily disturbed the efficiency of grouping. This argument may seem in contradiction with the previous finding (experiment 3), that in fact eyemovements are unnecessary in the stationary field. According to this finding, the subjects should be capable to group and respond to S_l and S_r efficiently, without making any eyemovements at all. On the other hand it was found that, without explicit instruction with respect to inspection strategy, eyeshifts belonged to the subject's preferred behaviour. The shift may be considered as a kind of final check of S_r and may be difficult to suppress if the subjects are not explicitly trained and instructed to avoid eye movements. If we start from this assumption, it follows that the eyeshift in the stationary field becomes a part of the grouping process so to speak, and the prohibition of the shift before the completion of Rt_l probably interferes with grouping. The interference will mainly lead to an increase of Rt_r, since the subject is thought to split up the original chunk: Discr. ($S_l + S_r$) in something like:

Discr. ($S_l + S_r$ partly) $\rightarrow$ Response S_l $\rightarrow$ completion S_r $\rightarrow$ response S_r.

The fact that Rt_r remains considerably shorter than Rt_l is a sign that an important part of the discrimination of S_r still takes place before the shift of the eye.

As said, the data of Exp. 7 demand a grouping process in the eyefield. It is likely however that this is not identical to that in the stationary field, since in that case behaviour would have been equally ineffective, so that Drop II would have disappeared too. Rt_r is significantly shorter in the eyefield than in the headfield however, and the only difference with Exp. 6 is that Rt_l tends to be longer at smaller display angles. This trend may reflect the extra time needed for the intake of two signals at once, but in that case it is curious that the lengthening of Rt_l was absent in the previous study (experiment 6). Another explanation can be that the obeyance of the instruction had an inhibitory effect on the length of Rt_l in the stationary field and in the eyefield. Accepting this line of thought, the natural process in the eyefield will deviate from that in the stationary field in such a way, that the grouping process is more easily interrupted by a response.

Before continuing this analysis, we will test the main hypothesis of this discussion i.c. that, when grouping is prohibited by instruction, reaction time is prolonged in the stationary field and the eyefield. A check of this idea can be provided by varying the instruction. If the subjects are instructed to treat the signals successively, we expect a relatively worse result in both the eyefield and the stationary field, compared with the explicit instruction to group the signals. In the headfield, grouping in the sense of formula 1 is supposed to be impossible. When subjects are instructed to collect the perceptual data first, we expect a process as expressed in formula 2b. This is supposed to be as efficient as that described in formula 2a, and no difference between the results is predicted therefore.

EXPERIMENT 8

METHOD AND PROCEDURE

The experimental setting was identical to that of exp. 7; only the instruction about the reaction strategy was varied. In one condition the subjects were instructed "to group" – i.c. to collect all perceptual data before responding; the responses could be given either in rapid succession or simultaneously. In another condition the subjects were asked "to treat the signals successively" – i.c. to neglect S_r until the reaction to S_l was completed. Before the experiment started, the subjects were trained in both strategies. To increase motivation, knowledge of results was given after each pair of responses. Per experimental session twenty pairs of correct reactions were obtained. 24 subjects took part in the experiment. They were randomly divided into three groups of 8 subjects. One group was tested at a display angle of 6°, the other at 66° and 99° respectively. All groups were tested twice, both with "grouping" and "successive treatment" of the signals. The order of the experimental conditions was counterbalanced.

RESULTS

The mean reaction times are given in table 15.

TABLE 15 - Mean reactiontime to ($S_l + S_r$) under different display angles and with varied instruction

Display angle	Grouping	Successive treatment	Significance
6°	.72	.87	$p < 0.01$
66°	.85	.97	$p < 0.01$
99°	.99	1.06	$0.1 > p > 0.05$

STATISTICAL TREATMENT

Per group an analysis of variance was carried out. Both at 6° and 66° the mean reaction time was significantly shorter at the instruction "grouping" $F = 14.35$ ($p < 0.01$) and $F = 17.35$ ($p < 0.01$). At 99° less evidence for a similar effect was obtained ($F = 5.25$ $0.1 > p > 0.05$, although the trend was again in the direction of a shorter Rt at the instruction "grouping". It is clear that the results of table 15 can be analysed only in the horizontal direction.
To examine how far the subject obeyed the instruction to group or to handle the signals successively, the separate response times to S_l and to ($S_l + S_r$) are listed in table 16.

TABLE 16 - Mean Rt_l and ($Rt_l + Rt_r$) under different instruction and display angle

	Display angle					
	6°		66°		99°	
Condition	Rt_l	($Rt_l + Rt_r$)	Rt_l	($Rt_l + Rt_r$)	Rt_l	($Rt_l + Rt_r$)
grouping	.65	.72	.79	.85	.90	.99
successive treatment	.46	,87	.44	.97	.43	1.06

Starting from the hypothesis that the instruction "successive treatment" has been obeyed, and that in general $Rt_l = Rt_r$, we expect that

$$Rt_l + Rt_r + m = (Rt_l + Rt_r)_{tot.}$$

Where m is the movement time of the eye. This factor can be estimated from previous results (see Exp. 6 and 7). Thus the following predictions of ($Rt_l + Rt_r$) are obtained:

6°: $.46 + .46 + .01 = .93$
66°: $.44 + .44 + .16 = 1.04$
99°: $.43 + .43 + .20 = 1.06$

Comparing the expected with the obtained data, it will be noticed that they fit only at 99°. Both at 66° (eyefield) and at 6° (stationary field), $(Rt_l + Rt_r)$ is about .07 sec. less than estimated. The significance of these divergences was tested by calculating the deviation between predicted and obtained $(Rt_l + Rt_r)$ for each individual and by estimation of the 5% confidence limits for the deviations (t-test). This delivered the following results:

6°:	$(Rt_l + Rt_r)_e - (Rt_l + Rt_r)$ obt. = .06	Conf. limits:	.039
66°:	$(Rt_l + Rt_r)_e - (Rt_l + Rt_r)$ obt. = .07	,, ,, :	.042
99°:	$(Rt_l + Rt_r)_e - (Rt_l + Rt_r)$ obt. = .00	,, ,, :	.000

DISCUSSION

In comment upon these results the following points arise:

1. Reaction by means of "grouping" delivers considerably better results than with "successive treatment". This is true for both the stationary field and the eyefield, but with much less evidence for the headfield. This finding confirms that instructions, which tend to "successive treatment" – as was the case in experiment 7 – will lead to ineffective behaviour in the stationary field and the eyefield, but not obviously in the headfield. For this reason drop I disappeared largely in exp. 7.
2. The instruction to handle the signals successively – and to neglect S_r until Rt_l had been completed – was not completely obeyed in the stationary field and the eyefield, while it was obeyed in the headfield. This confirms the results of exp. 7, where the subjects had great difficulty in responding to S_l before shifting to S_r. The present data show again that even with great emphasis on successive treatment Rt_r is less than Rt_l. This points again to the predominance of grouping and it strengthens the hypothesis that information about S_r is transmitted during inspection of S_l.
3. The instruction to group was obeyed quite well at all display angles. The rather short time difference between Rt_l and Rt_r was caused by the fact that some subjects responded to S_l and S_r simultaneously. Those subjects that responded successively showed a time difference of .15-.20 sec. between Rt_r and Rt_l.
4. Also in the headfield "grouping" tends to be the better strategy – although with much less evidence. This may be explained by the suggestion that after all some part of the transmission of S_l is carried out during the eye movement. This possibility was discussed earlier at page 74, and was left as a partial interpretation of the tendency to

shift to S_r before responding to S_l. As suggested on page 77, the evidence for the difference is much less cogent than at the other levels of the functional visual field, so that we can conclude that no grouping has occurred in the headfield but successive handling according to formula 2b.

2. *The selective process in the eyefield*

Summarising the evidence so far, it can be said that the results suggest a grouping process in the stationary field and the eyefield, which is modified to successive treatment in the headfield. It was suggested however, that the grouping process in the eyefield must differ from that in the stationary field. This was indicated already by the results of exp. 7; and also theoretically the application of Discr. $(S_l + S_r) \rightarrow$ response $S_1 \rightarrow$ response S_2 is not probable in the eyefield. The main objection lies in the fact that the selective act is likely to take place during a fixation pause of the eye, grasping those relevant signals that can be covered by peripheral vision. So during grouping, eye movements would not be necessary – although they may be preferred. Such is the case in the stationary field but not in the eyefield. Indeed, the reason that eye movements are required is, that peripheral viewing of itself is not sufficient to discriminate S_r.
Now, this does not imply however, that the effect of peripheral vision has disappeared completely in the eyefield. For the present experimental signals, the eyefield covers the area from 25° till 85°; and it has been found that the absolute light threshold at 50° nasal or temporal from the central fixation point proves to be still two percent of the maximal foveal value (Chapanis 1949). So the impression of S_r while fixating S_l may be a very vague one, but the possibility that a hypothesis about S_r is obtained cannot be excluded.
The importance of peripherally obtained information, has been clearly demonstrated in a recent paper by Poulton (1963). In an experiment on reading, subjects read typescript aloud through a window whose speed and size varied systematically. Errors increased significantly as the window was reduced from a full line to five words. Further evidence comes from a study of Senders, Webb and Baker (1955). Pointer positions on dials had to be read peripherally, showing an almost perfect discrimination if the instrument was displayed as much as 40° from the line of sight. Even at 80° over twice as many responses were correct than would have been predicted on a chance basis. The reason

for this experiment was the observation that the amount of time spent by pilots in the reading of any particular instrument in flight was much shorter than the time taken by subjects in a laboratory situation (Miller, Mc.Intosh and Cole 1954). The hypothesis was then developed that the images of the instruments, falling on the periphery of the retina, would convey some information, so that the range of possible alternative pointer readings is reduced and expectations can be formulated before actual fixation takes place. Another point that is stressed is the probable effect of experience on the display: on the one hand, perceptual anticipation – Poulton (1950) – is plausible in the pilot's situation and on the other hand, the knowledge about the characteristics of the instruments – form, extension etc. – may cause a decrease of reaction time. (Senders 1954).

The conclusion of Senders, Webb and Baker (op. cit) that "once an expectancy has been formulated, the principal function of a fixation on the instrument may be merely to confirm or reject it – a function that can be accomplished far more quickly than a quantative reading –" seems closely connected to our finding that Rt_r is shortened in comparison with Rt_l. On the basis of the obtained experimental data and this discussion, we can extend therefore our theory concerning the selective process. In the stationary field, the full grouping process as expressed in Discr. $(S_l + S_r) \rightarrow$ resp. $_1 \rightarrow$ resp. 2 remains. In the eyefield however we can suppose a "semi grouping" procedure like:

$$\text{Discr. } (S_l + \text{hypothesis } S_r) \rightarrow m \rightarrow (\text{check } S_r) \rightarrow \text{resp.}_1 \rightarrow \text{resp.}_2 \quad (3)$$

It will be clear that elements of both grouping and successive treatment are present in this formula. The "hypothesis S_r" can explain the natural tendency to shift to S_r before responding to S_l and also the shortening of Rt_r in Exp. 7. Furthermore obeyance of the instruction of Exp. 7 will be less serious than when complete information about S_r had been obtained, since, in fact, the "check S_r" is a second selective act and between two selective acts a response can be given according to the theory. Therefore the reaction times in the eyefield are less affected than in the stationary field. If the "hypothesis S_r" is completely suppressed however – as in exp. 8 – the process has to change from formula 3 to formula 2a – and this presumably leads to a decrease of efficiency.

A final advantage of this formulation is that it differentiates between the processes of the stationary field and the eyefield: Formula 3 is thought to be a more complex process than formula 1, and its application will take consequently more time. In this way, we may obtain an explanation of drop 1.

From this theory, predictions can be given for further experiments. One concerns the effect of training upon the ratio $Rt_l: Rt_r$. It can be stated from the preceding discussion that people without any experience in the task will take little advantage of the suggested possibility to express a hypothesis about S_r during inspection of S_l. Both in the eyefield and the headfield untrained subjects should deliver a low $Rt_l: Rt_r$, but not in the stationary field, where pure grouping is supposed to be predominant. In the latter area we expect therefore that Rt_r is shorter than Rt_l, even without any training. After training the ratio should agree with the results of experiment 7. A high ratio in the stationary field and the eyefield and a low one in the headfield.

EXPERIMENT 9

The same task was used as in the previous experiments: S_l and S_r – consisting of columns of dots (either four of five items) – were projected simultaneously on equal distances of the subject's meridian. Successive reactions were asked to S_l and S_r and the subjects were instructed not to shift the eye to S_r before Rt_l had been finished. 15 subjects – laboratory workers – were randomly divided in three equal groups. They were given extensive verbal instruction and training. So, when the experimental run started, they had no experience with the characteristics of the signals. The session was continued until 20 correct responses had been obtained. Those reactions where the eye had left S_r before Rt_l had been completed, were discarded from treatment.
After the experimental run the subjects got 8 training runs, in which the instructions were frequently repeated. Every training session consisted also of 20 correct reactions. Finally a second experimental run was carried out. As in exp. 7, onset of the signal, moment of reaction and eye and head movements were recorded. One group was tested under a display angle of 12°, the other groups under 57° and under 99° respectively.

RESULTS

For each subject the mean $(Rt_l: Rt_r)$ was obtained. The mean ratios per group are presented in table 17.

TABLE 17 - Mean ($Rt_l : Rt_r$) as a function of display angle and of training

	Display angle		
	12°	57°	99°
First exp. run:	1.63	1.16	1.06
Second exp. run:	1.71	1.40	1.01

STATISTICAL TREATMENT

An analysis of variance was carried out on the data of table 17. A significant difference between display angles was found ($F = 6.08$ $p < 0.02$). No evidence was present for a significant interaction between trials and display angles ($F = 2.54$ $0.1 > p > 0.05$), although some tendency was present. At the data obtained at 99°, there was no significant deviation from 1.00. This applied also to the data at 57° in the first experimental run. In the second experimental run the ratios were significantly higher than 1.00 at 57° (confidence limits from 1.12 to 1.68 (5% level)). At the display angle of 12°, a deviation from 1.00 was obtained both at the first and the second experimental run.

DISCUSSION

The data agree with the previous results since the ratio $Rt_l : Rt_r$ is significantly larger in the stationary field than in the headfield. In the headfield $Rt_l : Rt_r$ does not deviate from 1.00, which is predicted from the hypothesis that the signals are transmitted successively. In the stationary field Rt_r is considerable smaller than Rt_l, which agrees with the grouping hypothesis. Both phenomena are independent of training.
In the eyefield, we expected an increase of $Rt_l : Rt_r$ as a function of training. The results are ambiguous, since no significant increase between the first and second experimental run showed up, although the results were in the expected direction. The ratio increased for each subject but probably the number of subjects was too small to reach significance. In any case the ratio diverged significantly from 1.00 in the second experimental run, but not in the first run.
The shortening of Rt_r may still increase with more intensive training. No systematic experiment has been carried out to answer this point but the data of two highly experienced subjects support this idea. The subject A.S. reached a ratio of 1.95 at 57° and the subject J. Th. E. even obtained 2.66 at the same display angle.

In conclusion it can be said that the present data largely agree with the hypothesis about the $Rt_l : Rt_r$ ratio, as stated on page 82; they do support the theory that signals can be grouped to a certain extent in the eyefield.

3. Peripheral viewing of signals and perception during eye movements

The suggestion that the selective process in the eyefield passes off like formula 3 has been based so far mainly on data about reaction times and especially on the shortening of Rt_r. It is possible to test the theory in a more direct way however.
If during the selection of S_l also an hypothesis about S_r is obtained, we expect that the subjects are capable of expressing this hypothesis before the eye has moved from S_l to S_r, or during this movement. So, if S_r is presented for a short time while the subject is fixating S_l, it is predicted that the subject can judge S_r better than chance – although the confidence about the judgement will be little.
The verification of this hypothesis is essential for the theory, since the shortening of Rt_r, the tendency to shift to S_r before responding to S_l and the signs for an increased $Rt_l : Rt_r$ ratio as a function of training, may still be explained by means of perception of S_r during eye movements. If information about S_r is obtained during the eye movement, instead of together with S_l, we cannot speak about grouping although Rt_r is likely to be shortened in that case. It can be assumed that the hypothesis about S_r is more easily obtained after some training, whether it occurs during the eye movement or together with S_l. The tendency to shift to S_r and the more efficient reaction if one is instructed to group is more difficult to explain by perception during eye movements. It may be understood as follows however: if one obtains only information about the position of S_r after the selection of S_l, the tendency to shift to S_r may be aroused while the information about S_r itself is only obtained during the eye movement. In the headfield no information about the position of S_r may come through so that the tendency to shift to S_r can be more easily suppressed in that case.
There are other difficulties about this theory however. First the phenomenon that perception of static objects during saccadic eye movements is known to be virtually impossible – as was discussed already in an earlier context. It remains possible however, that our

signals exceed the threshold for perception during eye movements. It should be noted also that the perceptual suppression has been found mainly in situations where the signal-to-perceive was intermediate between two reference signals, between which the eye shifted. It is possible that the phenomenon is different if the aiming point itself has to be perceived – as is the case in our situation. Secondly we can wonder why – in the case of perception during the eye movement – this phenomenon disappears in the headfield. It requires the auxilary hypotheses that head movements disturb the entering of information during the eye movement. It is difficult to see why.
Assuming perception during the eye movement, however, an explanation is offered for most findings in the eyefield and it should be considered together with our grouping theory. It must be emphasised that the theories are not completely mutually exclusive. If we start with the grouping theory, which predict an hypothesis about S_r in an early stage of the persentation, it may be said that the expectancy is strengthened during the eye movement.

EXPERIMENT 10

METHOD AND PROCEDURE

The general set-up of the experiment was nearly the same as that of exp. 7. The only difference concerned the presentation time of S_r: As in exp. 7, both S_l and S_r arrived simultaneously but S_r disappeared after 0.3-0.6 sec. Depending on the latter presentation time and on the speed of Rr_l, S_r disappeared either during the eye movement or during the fixation of S_l or also when S_r was already fixated.
The instruction was also similar to that of exp. 7: S_l should be responded to before the eye was shifted. In view of the difficulties, which were met with in exp. 7, the subjects were trained until they were able to start the eyeshift at the moment that Rt_l was completed. Another difference with exp. 7 was that no Rt_r was asked but only a forced choice judgment with regard to S_r. Further the subjects were asked to express their confidence about the judgment on a five points rating-scale, indicating 1. pure guessing 2. very insecure 3. dubious 4. sure 5. quite sure.
In total 4 subjects were tested at display angles on the border of the eyefield and the headfield. For every subject the null hypothesis was tested by means of χ^2 technique after correction for continuity.

TABLE 18 - Survey of correct and false judgements on S_r as a function of display angle and eyeposition. (The moments at which S_r disappeared were divided into four classes: I, S_r disappeared at least 0.08 sec. before the eyemovement started; II, idem but from 0.00-0.08 sec; III, S_r disappeared during the eyemovement; IV, S_r disappeared 0.00-0.08 sec. after the eye had reached S_r).

Subject	Periods in which S_r disappeared	Number of responses correct	false	χ^2	Confidence value (average rating)
		Display angle 66° (eyefield)			
	I	4	7	—	1.1
J.M.	II	25	11	$p < 0,05$	1.4
	III	40	6	$p < 0.01$	2.8
	IV	14	0	$p < 0.01$	4.0
A.F.S.	I	21	5	$p < 0.01$	1.8
	II	37	18	$p < 0.02$	2.0
	III	85	22	$p < 0.01$	3.2
	IV	14	0	$p < 0.01$	4.9
Th.E.	I	18	3	$p < 0.01$	2.4
	II	28	1	$p < 0.01$	2.6
	III	34	8	$p < 0.01$	2.8
	IV	10	0	$p < 0.01$	4.1
B.S.	I	3	3	—	1.2
	II	18	3	$p < 0.01$	1.7
	III	49	13	$p < 0\ 01$	1.7
	IV	17	2	$p < 0.01$	4.4
		Display angle 81° (eyefield)			
J.M.	I	3	2	—	2.2
	II	15	8	$p > 0.05$	2.4
	III	36	10	$p < 0.01$	2.7
	IV	15	1	$p < 0.01$	4.2
A.F.S.	I	38	18	$p < 0.02$	1.8
	II	38	14	$p < 0.01$	1.7
	III	51	11	$p < 0.01$	2.2
	IV	13	0	$p < 0.01$	4.5

Subject	Periods in which S_r disappeared	Number of responses correct	false	χ^2	Confidence value (average rating)
Th.E.	I	2	2	—	2.5
	II	13	1	$p < 0.01$	2.5
	III	28	3	$p < 0.01$	3.1
	IV	12	0	$p < 0.01$	5.0
B.S.	I	4	2	$p > 0.05$	1.0
	II	5	4		1.5
	III	31	16	$p < 0.05$	1.7
	IV	18	0	$p < 0.01$	4.0
		Display angle 88° (headfield)			
J.M.	I	3	4	$p > 0.05$	2.7
	II	15	8		2.4
	III	49	15	$p < 0.01$	3.0
	IV	17	0	$p < 0.01$	4.9
Th.E.	I II	5	4	—	1.6
	III	23	13	$p > 0.05$	2.0
	IV	12	0	$p < 0.01$	4.8
B.S.	I				
	II	5	4	$p > 0.05$	1.1
	III	40	20	$p > 0.05$	1.4
	IV	18	4	$p < 0.01$	3.5
		Display angle 94° (headfield)			
J.M.	I II	5	4	$p > 0.05$	1.5
	III	24	20	$p > 0.05$	2.4
	IV	10	0	$p < 0.01$	5.0
A.F.S.	I	10	13	$p > 0.05$	1.5
	II	8	7	$p > 0.05$	1.6
	III	46	25	$p < 0.02$	1.7
	IV	24	3	$p < 0.01$	4.2
		Display angle 99° (headfield)			
A.F.S.	I II	9	18	$p > 0.05$	1.1
	III	34	27	$p > 0.05$	2.1
	IV	9	0	$p < 0.01$	3.9

The same apparatus was used in the previous experiments (see fig. 5) with the addition of extra shutters that were placed before the projectors which presented S_r. They were opened at the same time as the original shutters, but they closed after a presentation time of 0.3-0.6 sec The exact presentation time of S_r was varied according to the subjects speed of reaction to S_l. It was the aim to obtain measurements at various values during and before the eye movement. Both the spread of reaction times to S_l and the variation of the presentation time were helpful to arrive at this goal.

RESULTS

The data are presented for each subject in table 18.

It appears from these results that within the eyefield the number of correct judgments is much larger than would be expected on a chance basis. This applies both to the measurements where S_r disappeared during the eye movement and to those, where this happened before the eye had left S_l. At the start of the headfield these phenomena disappear. This is summarised in table 19.

DISCUSSION

The results of experiment 10 show the possibility to obtain an idea about S_r, while responding to S_l – as long as the display angle does not exceed the eyefield. In view of the very low level of subjective confidence – that never goes beyond a mean value of 2.5 for the classes I and II – it should be recognized that "this idea" must be considered as a vague hypothesis rather than a secure judgment. This is in complete accordance with our prediction and also with the findings of Senders Webb and Baker (op. cit.). It may be wondered, however, whether the peripheral impression of S_r is still strengthened during the eye movement. Experiment 10 is less apt to answer this question since it is not possible to separate the peripheral effect. Only a few indications can be noted.

1. If during the eye movements further information about S_r is conveyed, we would expect a fair increase of the subjective level of confidence in class III. In general, no striking increase is present. Also during the eye movement the impression about S_r is still vague.

TABLE 19 - Summary of the statistical significance of the results ~~in experiment~~ 8

(— = not significant; + = $p < 0.05$; ++ = $p < 0.02$; +++ = $p < 0.01$. O = too few measurements to decide)

Visual angle

subjects	66° J.M.	66° Th. E.	66° A.F.S.	66° B.S.	81° J.M.	81° Th. E.	81° A.F.S.	81° B.S.
eye position I	O	+++	+++	O	O	O	+	—
II	+	+++	++	+++	—	+++	+++	—
III	+++	+++	+++	+++	+++	+++	+++	+
IV	+++	+++	+++	+++	+++	+++	+++	+++

subjects	88° J.M.	88° Th. E.	88° B.S.	94° J.M.	94° A.F.S.	99° A.F.S.
eye position I	—	—	—	—	—	—
II	—	—	—	—	—	—
III	+++	—	—	—	++	—
IV	+++	+++	+++	+++	+++	+++

Supposing however, that only at the end of the eye movement information comes through, the average value of all data can have obscured the increase. Therefore, in table 20 more detailed data about the level of confidence in judging S_r during the eye movements are given. Here, only, the measurements within the eyefield are taken into account, since it is quite sure that beyond the eyefield no information is gathered during eye and head movements.

It appears that a gradual increase of confidence does occur, which seems to be more outstanding at the second half of the eye movement. Only subject B.S. remained very hesitant in his judgments until class E. This result seems to support the possibility of intake of information at the end of the eye movement, strengthening the impression obtained in peripheral viewing during the fixation of S_I.

2. Another argument may be still obtained in favour of some perceptual activity during the eye movement. Inspecting table 19, we notice that all subjects – except Th. E – showed a rather gradual decrease in significance of correct responses. So, at first the subject becomes

TABLE 20 - Increase of confidence in judging S_r during eye movements (combined data of 66° and 81°)

	Eyeposition						Eyeposition				
Subject	A	B	C	D	E		A	B	C	D	E
J.M.	1.7	2.4	2.7	3.2	3.8	Average rating	2.0	2.1	2.4	3.1	4.0
A.F.S.	1.9	2.1	2.3	4.0	4.6						
Th.E.	2.6	2.4	2.9	3.6	4.0						
B.S.	1.8	1.7	1.7	1.8	3.8	Normalised Scale values ($\sigma = 2.00$)	— 2.7	— 1.4	— 0.8	+ 1.5	+ 2.8

A = S_r disappeared 0-0.04 sec before eye movements starts
B = „ „ 0-0.04 „ after „ „ „
C = „ „ 0.04-0.08 „ „ „ „ „
D = „ „ 0.08-0.12 „ „ „ „ „
E = „ „ 0.12-0.16 „ „ „ „ „

N.B. The mean movement time is about 0.15 sec. for these display angles, so that in class E, fixation has been possible in many cases.

unable to judge S_r while responding to S_l and only at a larger visual angle the significance disappears in class III. This may point to a joint effect of peripheral viewing and perception during eye movement at smaller visual angles.

As has been said these points can serve as indications for perceptual activity during eye movements. To tests the hypothesis more directly exp. 10 will be repeated with the difference that S_r is only visible during the eye movement.

EXPERIMENT 10a

METHOD AND PROCEDURE

Using the same set-up as in exp. 10, the subjects were instructed to shift the eye from S_l to S_r as soon as the former signal appeared. S_r was given .2 sec. after S_l and was presented for 0.12 sec. Those measurements were treated where S_r was only present during the eye movement. This could be observed from the graphical recorder, where both eye movements and moments of arrival and departure of S_r were registrated. As control experiment it was ascertained whether the subjects could judge S_r, if it was fixated or if it was peripherally

TABLE 21 - Correct responses to S_r, being presented during the eye movement and during peripheral viewing

Subject	Number of responses correct	false	χ^2	Confidence level average rating	
J.M.	22	12	$p > 0.05$	3.1	
A.F.S.	40	27	$p > 0.05$	2.1	
Th. E	19	14	$p > 0.05$	2.0	during the eye-movement
B.S.	24	13	$p > 0.05$	1,6	
Total	105	66	$p < 0.01$		
J.M.	28	8	$p < 0.01$	2.8	
A.F.S.	30	6	$p < 0.01$	2.1	
Th. E	30	6	$p < 0.01$	3.7	during peripheral viewing
B.S.	26	10	$p < 0.02$	1.5	
Total	114	30	$p < 0.001$		

viewed. The results were obtained at 66° and are listed in table 21.
It is clear that discrimination of S_r is much better, if S_l is fixated than if the discrimination is made during the eye movement. When the results during peripheral viewing are taken as the expected relation for those during eye movements, we get a χ^2 of 19.0 which is also highly significant. The results obtained at the fixation of S_r are not presented, since all subjects delivered 100% correct responses, which is much better than during both eye movements and peripheral vision. During eye movements the subjects did not show a result better than "chance", although they were all in the positive direction. Taking the results of all subjects together, we see that the judgment of S_r is better than would be predicted on a chance basis. We cannot reject the hypothesis therefore, although it is quite certain that the intake of information about S_r during eye movements will be quite small. It may be that the correct responses occur more often, when the signal is presented in the last, rather than in the first half of the eye movement, as was suggested above. This was difficult to prove from the data of experiment 10a, since the signal was always covering a very big part of the eye movement. It was presented for .12 sec. while the eye movement lasted about .15 sec.
Definite evidence about the intake during eye movements may be

obtained by presenting S_r while the eye movement is carried out, and by asking a reaction. In the case of perceptual activity we expect a shortening of Rt_r – as was found in experiment 6 and 7.

EXPERIMENT 10b

METHOD AND PROCEDURE

A similar set-up was used as in exp. 10a. The arrival of S_l was used as a mere sign to shift the eye to S_r; S_r appeared 0.2 sec. after S_l, so that peripheral viewing was impossible. S_r remained also after the completion of the eye movement. Instead of a judgment, a discriminative reaction was asked. In a control experiment, Rt_r was determined while S_r was fixated from the start of the presentation. 3 highly trained subjects were tested.

RESULTS

The median values of series of twenty signals for each condition of the three subjects are presented in table 22.

TABLE 22 - Median data on Rt_r (simple) and Rt_r (preceded by eye movement)

Subject	Rt_r (preceded by eye movement)	Rt_r (simple)
A.F.S.	.36	.37
Th.E.	.44	.42
L. de K.	.38	.32

Even without the application of statistical techniques it is clear that no evidence is present for a shortening effect of Rt_r under these circumstances. The very small effect of perception during eye movements cannot be traced it reaction to S_r is asked. Probably the hypothesis, that is obtained, is too deficient to exert an effect. It can be maintained however, that a hypothesis, obtained during fixation of S_l, can be strengthened during the eye movement – witness the increasing confidence level in exp. 10.

A final experiment in this series was devoted to performance at the borders of the stationary field and the eyefield. As to the results we can readily assume that judgments will be much better than guessing. As to the confidence values, in the stationary field – where pure grouping is supposed – we expect accordingly a very high level of confidence; in the eye field it will decrease.

EXPERIMENT 10c

METHOD AND PROCEDURE

The whole experimental set-up was equal to that of exp. 10. Only the range of measurement was different; between 12° and 47°, instead of between 66° and 99°. In view of the fact that no eye movements are required in the stationary field – the presentation time of S_r was kept very small: 0.1 sec. The results of 4 subjects are listed in table 23.

TABLE 23 - Survey of correct and false judgments on S_r and the mean confidence value at each display angle

Subjects	Number of responses: correct	Number of responses: false	Level of confidence: Average rating	Level of confidence: Normalised scale value ($\sigma = 2.00$)
		12° stationary field		
J.M.	21	0	5.0	
A.F.S.	20	1	4.8	
Th.E.	18	4	4.2	+ 3.6
L. de K.	19	2	4.7	
		24° stationary field		
J.M.	21	1	4.3	
A.F.S.	26	1	4.7	
Th.E.	22	1	4.2	+ 3.4
L. de K.	17	3	4.7	
		36° eyefield		
J.M.	17	3	3.4	
A.F.S.	23	3	3.5	
Th.E.	18	5	3.3	+ 1.3
L. de K.	17	3	3.6	
		47° eyefield		
J.M.	18	4	3.0	
A.F.S.	20	4	2.8	
Th.E.	18	2	3.0	—0.6
L. de K.	18	1	3.6	

DISCUSSION

The predictions about the results are largely confirmed. In no case could the difference between correct and false responses be ascribed to "chance". Furthermore the confidence value tends to decrease considerably if the display angle exceeds the stationary field.

Summarizing the evidence of exp. 10 we can state that the results are in accordance with our theory about the selective process in the functional visual field. It is shown especially that the possibility to formulate an hypothesis about S_r is really present in the eyefield. Grouping is likely to play still an important role in the eyefield. An interesting phenomenon is thus that the changes of the selective process are so clearly connected with the anatomy of the organism: the region of clear vision in the transition from stationary field to the eyefield and the size of the eyeball in the transition from eye- to headfield.

4. *The role of grouping in the psychological refractory period*

In this section we will consider the role of the grouping process in the psychological refractory period. This topic has been briefly touched upon before (page 20 and 70); as mentioned, it arose from the observation that, when two signals are presented in rapid succession, the reaction time to the second signal (Rt_2) is retarded in comparison with that to the first signal (Rt_1). The original result of Telford (1931) was reconsidered after World War II in Britain and during the last decade a large number of experiments have been carried out.

The similarity between our experiments and those on the psychological refractory period clearly exists: in both cases we meet an experimental set-up, where two signals are presented in order to be reacted upon; in several studies on the psychological refractory period, the signals came also from separate sources. The major differences concern successive- instead of simultaneous presentation and, secondly, in most studies on "refractoriness" a simple reaction to light was asked instead of a choice reaction. In spite of these differences, we expect that grouping will be important in the psychological refractory period, especially if the intersignal interval is small.

In fact grouping has been reported; Welford mentions it explicitly (1952, 1959) to explain those cases, where no delay in Rt_2 occurred. It was not found however in a series of experiments by Davis (1956, 1957, 1959). In the latter studies, successive treatment of the signals took place exclusively. In recent papers of Davis (1962) and Borger (1963), however, successive treatment was much less clear.

Successive treatment has also not been found by Elithorn and coworkers (Elithorn and Lawrence 1955, Halliday, Kerr and Elithorn 1960). In their experiments a choice reaction was asked and especially at small intervals between S_1 and S_2, no delay of Rt_2 appeared. This was not explained in terms of grouping however. Rather, Elithorn et al. rejected an explanation in terms of the single channel theory altogether, holding that the organism is capable of transmitting several signals at the same time, along different neural pathways.

Their argument runs as follows: in the usual experimental design, the intersignal interval is varied within one experimental series, so that the subject is never sure about the actual interval at a given stimulus pair – although he may have an expectation. The latter point is emphasised. It is argued that the subject has a general state of expectation about the arrival of S_1 and S_2. When S_1 arrives, this expectancy is temporary lessened, but increases again as a function of time. Since expectancy and reaction time show an inverse relationship (Mowrer 1940), Rt_2 should be large at the minimum level of expectancy. In this way it is possible to explain the delay of Rt_2: shortly after S_1 – say 0,15 sec. – the state of expectation reaches a minimum, so that Rt_2 will be large at that interval. At still shorter intervals the level of expectancy is supposed to be higher, so that Rt_2 will become smaller – and, indeed, this occurs in some cases, especially those, where Welford suggested a grouping process.

The bottle-neck of this theory is – as Broadbent (1958) pointed out – that no delay of Rt_2 is predicted if the intersignal interval is kept constant. The possible effect of the level of expectation is eliminated in that case. Now Fraisse (1957) kept the interval constant and found a decrease of the delay, although it did not disappear completely. His subjects were relatively untrained in the task however and they tended to make very large delays – much larger than predicted by the formula of Davis. Another complication in the work of Fraisse was the clear tendency towards anticipation of S_2 if a simple reaction to light was asked. Davis (1962) failed to find the usual delay if I was constant. To avoid anticipation, he used choice reactions, instead of the traditional simple reactions. Thus, the hypothesis of Elithorn et al. is supported in so far that the delay of Rt_2 tends to diminish if I is constant and – this may be important – if choice reactions are asked.

However, this is no reason to accept the multichannel theory. It can be supposed that, under the latter conditions, the selective strategy changes from successive treatment to grouping. This suggestion can be used to explain the lack of the grouping effect in the traditional experiments, in which I is varied from 0.05-0.5 sec. in steps of 0.05 sec. and in which all possible intervals occur randomly in one and the same test session. In analogy with Helson's adaptation level theory (Helson 1958), expectancy reaches the highest level in the middle of the possible range of intervals, all intervals being equiprobable, and may decrease somewhat at very great intervals. A consequence of this theory would be that the subject expects S_2 to arrive some 0.25 after S_1 – at which interval he may prefer to handle them successively. His whole strategy will be into this direction, therefore, and it has been shown in earlier sections that such a strategy is possible, even when the signals arrive always simultaneously. Only, this strategy proved to be less efficient than grouping.

A differentiation between grouping and successive treatment on the one hand an multichannel transmission on the other hand, is aimed at by Halliday, Kerr and Elithorn (1959). Since the results of this study seem crucial to the whole idea of grouping, the paper will be discussed at some length. Anticipation was avoided in the experiment by introducing uncertainty about the arrival of S_2. In one quarter of the measurements, S_2 was omitted, while in the remaining presentations S_2 followed upon S_1 with a nearly constant interval (50, 100 ms). The intention of the authors was to decide between unichannel or multichannel processing and three possible relations between Rt_1 and Rt_2 were formulated.

1. Simultaneous transmission – as predicted by the multichannel view and leading to $Rt_1 = Rt_2 = Rt_0$ (where Rt_0 stands for the reaction time when only one signal is presented).
2. Successive treatment – as predicted by the unichannel theory, expressed by $Rt_2 = 2Rt_1 - I$.

Thirdly the possibility of the grouping process is taken into account. The reaction times predicted by this assumption can be expressed by:

$$Rt_2 = Rt_1 - I + c \; (Rt_2 > Rt_0;\ I < 0.1 \text{ sec.}),$$

where c is a constant, depending on the speed at which the motor part of Rt_2 is carried out after that of Rt_1. If both responses are made simultaneously c equals zero. It should be recognized in this respect that grouping is considered to be a perceptual rather than a motor process; successive responses to S_1 and S_2 should not be taken as incompatible with grouping, as is suggested by Halliday et al. (1960 p. 73) – (See also Welford 1959).

The results of the experiment are interpreted by the authors as supporting the multichannel hypothesis: Rt_1 was found equal to Rt_2 and moreover Rt_1 was equal to Rt_0. The value of the latter was

obtained from the presentations where S_2 was omitted, so that logically the reaction time to a single stimulus was measured.
In fact, it is hard to believe that this way of measuring Rt_0 is valid; assuming a predominance of grouping for a moment, the subject is supposed to postpone the treatment of S_1 until S_2 has arrived. There is no obvious reason why this "delay of Rt_1" would not occur when S_2 is omitted, since the subject will probably expect S_2 to come. The expectancy argument – used so frequently by the authors – returns to criticise their own interpretation. But also the conclusion that Rt_1 is equal to Rt_2 cannot be used in favour of the simultaneous transmission theory, since the reaction times are not equivalent. In the experiment two clusters of miniature neon bulbs were used: S_1 was presented by flashing one of both clusters. Which one was randomly decided, so that a choice reaction was asked; S_2 always consisted of the alternative cluster. Thus after the presentation of S_1 the only uncertainty about S_2 was about its appearance at all. Marill (1957) using a similar stimulus sequence, rightly states: "The comparison between Rt_1 and Rt_2 is not altogether satisfactory, for we must realise that the conditions, under which Rt_1 is made, are not the same as those under which Rt_2 is made. It is probable more meaningful to compare the Rt_2 only among themselves".

It appears from this discussion that the experiments on the transmission of successive signals with a constant interval between S_1 and S_2 have failed to provide valid evidence about the occurrence of multi- or single-channel transmission. Consequently the role of grouping in the psychological refractory period remains obscure. To contribute to this discussion, an experiment was designed in which the following conditions were fulfilled: S_1 and S_2 were comparable stimuli; Rt_1 and Rt_0 were measured in separate experimental sessions. Anticipation was avoided by introducing successive choice reactions, instead of simple reactions.

EXPERIMENT 11

METHOD AND PROCEDURE

The subject was seated at a table on an adjustable chair at a distance of 70 cm from a screen. S_1 and S_2 were projected slightly above eye-level and respectively left and right form the subjects meridian. The distance between S_1 and S_2 was 7.5 cm, forming a visual angle of

6° with the subject. Both S_1 and S_2 consisted of the usual columns of dots. The task consisted of two successive discriminative reactions, one to S_1 (four or five dots) and another to S_2 (idem). Four morse-keys, corresponding to the possible signals, were fixed on the table, behind which the subject was seated and they served as reaction-set. The response to S_1 was given with the left hand and that to S_2 with the right hand. The alternatives of S_1 and S_2 (4, 5 dots) had an equal chance of occurrence; 3 seconds before the arrival of S_1, a visual warning signal was presented on the spot where S_1 was to appear. The interval between S_1 and S_2 was constant within an experimental series. Between series it was varied, being (0.0 sec; 0.1 sec; 0.2 sec; 0.3 sec or 0.4 sec.).
The apparatus was similar to that used previously (see fig. 5). The warning signal (W) was given immediately after the apparatus had been put to work. The presentation took place by opening the shutter, placed before the appropriate projector. At the same time S_1 and S_2 were selected by the stimulus selector and after a time-delay of 3 sec. the shutters of S_1 and S_2 were opened. Thus S_1 became visible, while S_2 was held back for a moment, until a second pair of shutters was openend, after a time-delay of $(3 + x)$ sec. from the start (the time x was varied from 0.0 sec. to 0.4 sec.).
Reaction times were measured by means of two time-counters, that were started at the presentation of S_1 and were stopped after the response to S_1 and S_2 respectively. The correctness of the responses was checked by a set of lights, indicating the stimuli and the responses (see fig. 16).

6 subjects – laboratory workers, aged from 25 to 35 years – took part in the experiment. They performed 6 experimental series in a Latin square order. Each series consisted of twenty presentations and choice responses to S_1 and S_2. In five series the variable was the inter-stimulus interval, as indicated above. A sixth series was introduced in order to measure Rt_0. From the reaction times the median value was calculated for each series. Before the experiment started, the subjects got some training on all possible conditions, but they could not be considered to be well-trained, when they performed the experimental series.

RESULTS

The means of the median reaction times to each of the six experimental

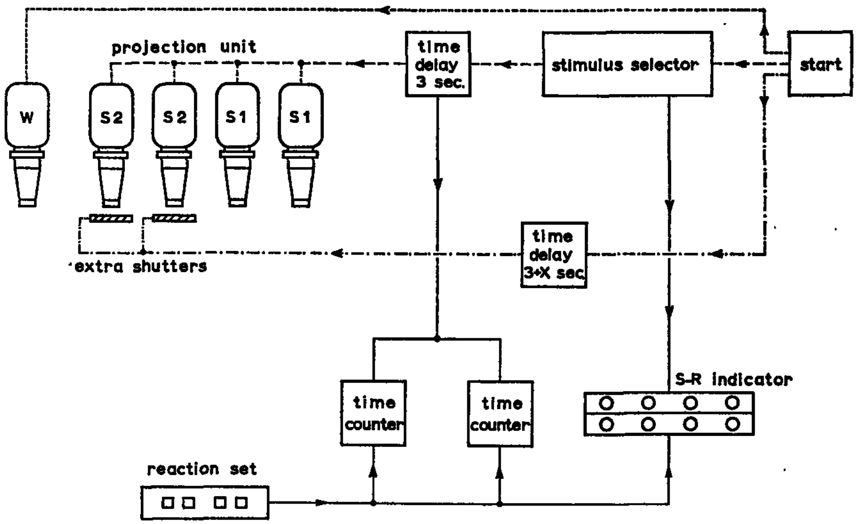


FIG 16 - Schematic drawing of the apparatus

conditions are represented in table 24. The predicted values – on the basis of grouping, successive handling or simultaneous transmission – are given for comparison.

TABLE 24 - Means of median reactiontimes to S_1 and S_2 as a function of I, compared with the predicted values.

Interval (S_1S_2)	Obtained results Rt_1	Rt_2	Predicted results for Rt_2 grouping	successive handling	simultaneous transmission
0.0 sec	.63	.76	.78	1.26	.63
0.1 sec	.59	.69	.64	1.09	.59
0.2 sec	.53	.60	.48	.85	.53
0.3 sec	.54	.53	.39	.78	.54
0.4 sec	.49	.51	.24	.58	.49
Rt_0:	.40				

STATISTICAL TREATMENT

1. After a square root transformation, due to heterogenity of variance, an analysis of variance was carried out on the median values of Rt_1 and Rt_0. A significant decrease of Rt_1, as a function of I appeared ($F = 5.95, p < 0.01$) Appropriate t-tests showed that a difference

of 0.097 sec. was necessary between two means to reach the 5% level of significance.

2. A similar procedure was applied to the median values of Rt_2 and Rt_0, *delivering a highly significant effect "between intervals"* ($F = 23.70$, $p < 0.001$). Between two means, a difference of 0.096 sec. was needed to reach the 5% level of significance.

In commenting on these results, it is remarkable that the data obtained at $I = 0.0$ sec. and 0.1 sec. clearly fit the grouping prediction, for Rt_1 is considerably longer than Rt_0 and – apart from random variation – Rt_2 equals the prediction.
The picture is less clear at $I = 0.2$-0.4 sec. As to the value of Rt_2 the simultaneous transmission hypothesis fits very well, but the condition that Rt_1 equals Rt_0 is not fulfilled – exept perhaps at $I = 0.4$, where the difference between Rt_1 and Rt_0 just fails to reach significance. The successive treatment process is not present at all in those data and so far the results are in agreement with the work of Davis (1962) and Borger (1963).
The inconsistency of the data at the larger intervals can be due to individual differences: some subjects may persist to group, while others handle the signals successively. It is useful therefore to consider the individual medians separately, as is done in table 25.

DISCUSSION

The individual median reaction times again stress that grouping was predominant at $I = 0.0$ sec. and 0.1 sec. Some subjects apparently persist in grouping until $I = 0.3$ sec., while the results of the remaining subjects are difficult to interpret. Neither successive treatment nor simultaneous transmission seems to fit the data. The latter process must be rejected mainly since Rt_1 is nearly always larger than Rt_0, which fact suggest that the signals are not transmitted independently. Instead, the arrival of S_2 affects the length of Rt_1.
Following Broadbent (op. cit.) we can assume that the condition $Rt_1 = Rt_0$ is not completely crucial for the multichannel theory, since the auxiliary hypothesis can be introduced that in the Rt_0 measurements two independent channels are combined into a single channel of higher capacity allowing a more rapid transmission. In that case the channels are not completely separate however and the assumption tends to blunt the difference between uni- and multichannel theory.

TABLE 25 - Individual median values of Rt_1 and Rt_2. For each subject, c. was estimated on the basis of a post experimental trial, where the subject was instructed to group the signals at I = 0.00.

	Interval 0.0 sec		0.1 sec		0.2 sec		0.3 sec		0.4 sec	
	Rt_1	Rt_2	Rt_1	Rt_2	Rt_1	Rt_2	Rt_1	Rt_2	Rt_1	Rt_2
B.S. (c = 0.15 sec)										
Obtained	.53	.68	.66	.76	.56	.56	.54	.45	.47	.42
grouping		.68		.71		.51		.39		.22
successive treatment		1.06		1.22		.92		.78		.54
simult. transm.		.53		.66		.56		.54		.47
J.M. (c = 0.15 sec)										
Obtained	.72	.87	.77	.83	.53	.81	.47	.63	.53	.55
grouping		.87		.82		.48		.32		.28
successive treatment		1.44		1.44		.86		.64		.66
simult. transm.		.72		.77		.53		.47		.53
C.v.d.Z. (c = 0.20 sec)										
Obtained	.57	.76	.50	.61	.48	.51	.48	.42	.35	.39
grouping		.77		.60		.48		.38		.15
successive treatment		1.14		.90		.76		.66		.30
simult. transm.		.57		.50		.48		.48		.35
J.V. (c= 0.0 sec)										
Obtained	.78	.78	.77	.68	.68	.56	.67	.57	.55	.51
grouping		.78		.67		.48		.36		.15
successive treatment		1.56		1.44		1.16		1.02		.70
simult. transm.		.78		.77		.68		.66		.55
L. de K. (c = 0.10 sec)										
Obtained	.53	.63	.45	.64	.39	.57	.59	.57	.47	.55
grouping		.63		.45		.29		.39		.17
successive treatment		1.06		.80		.58		.88		.54
simult. transm.		.53		.45		.39		.59		.47
J.M.S. (c = 0.25 sec)										
Obtained	.65	.90	.40	.62	.53	.58	.60	.57	.58	.63
grouping		.90		.55		.58		.55		.43
succes. treatment		1.30		.70		.86		.90		.86
simult. transm.		.65		.40		.53		.60		.58

As to our results we can wonder, why the simultaneous transmission did not hold for all intervals: once postulated, the multi-channel theory should be able to predict Rt_2 for all intervals, smaller than Rt_1. At $I \leqslant 0.1$ sec. however, we found grouping predominant. This difficulty may be solved by accepting a second auxiliary hypothesis, i.c. that simultaneous transmission occurs only during the central organising period and that the motorparts of Rt_1 and Rt_2 are carried out successively. Accepting this point, the difference between grouping and simultaneous transmission has disappeared for $I < c$, so that the results at $I = 0.0$ sec. and 0.1 sec. can be explained in terms of the multichannel view.

It should be remembered however, that a pure multichannel theory is not maintained in this way. What remains of the idea is only that during transmission the signals are transmitted either separately or simultaneously by more channels, which can be combined when the situation requires such processing. As said, the two auxiliary hypotheses tend to diminish strongly the difference between uni-channel and multichannel theory.

Starting from the single channel theory, difficulties also seem to arise; although the results at 0.0 sec. and 0.1 sec. interval can be satisfactorily explained by means of grouping, we may wonder which process occurs between 0.2 sec. and 0.4 sec. interval. Neither grouping nor successive treatment fitted these results. This last remark seems premature however. It is admitted that successive treatment according to Discr. $S_1 \rightarrow$ Response $S_1 \rightarrow$ Discrimination $S_2 \rightarrow$ Response S_2 is absent. But, as was argued in the beginning of this chapter, the successive treatment may run otherwise, namely according to: Discr. $S_1 \rightarrow$ Storing $S_1 \rightarrow$ Discr. $S_2 \rightarrow$ Response $S_1 \rightarrow$ Response S_2. If we assume that at the arrival of S_2, the processing of S_1 is momentarily interrupted to store S_2 – say during 0.1 sec. – we obtain the following predictions (see fig. 17).

Comparing the predicted results with those obtained, a nice agreement is shown. Thus assuming a successive treatment process according to formula 2b (page 69), the difficulty might be solved. Successive treatment according to formula 2a may appear an extreme selective strategy, which is easily substituted by that of formula 2b.

The question remains however, why the latter process is generally found in choice reaction tasks, while the former strategy is apparently applied in simple reaction situations. The answer may be, that an

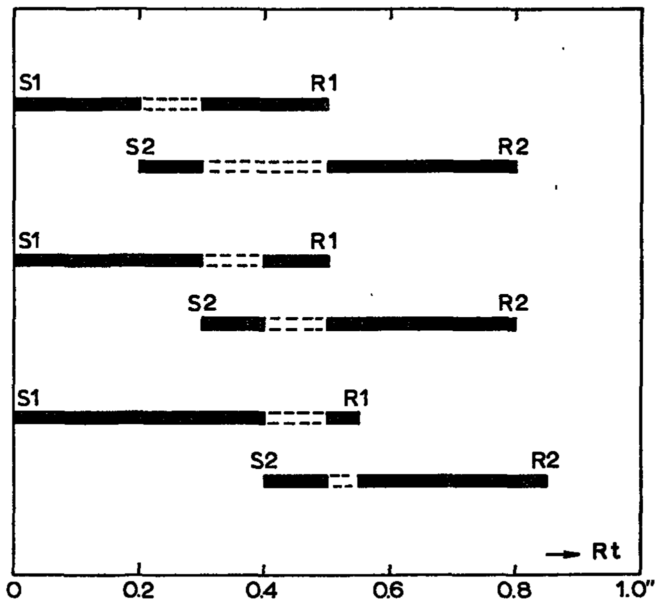


FIG. 17 - The assimilation of successively presented signals
Prediction of reaction times from a hypothetical scheme

interruption of an S-R process is less often found in simple reactions to light, since this type of reactions "closely resembles a reflex and is in effect a temporary prepared reflex" (Woodworth and Schlosberg 1954). Above the reflex level, human behaviour is less bound to a specific type of reaction, and the perceptual strategy can be varied more easily.

This discussion is restricted to the intervals 0.2 sec.-0.4 sec. It can be seen from table 24 that at 0.1 sec. Rt_1 is increased so much, that the difference between Rt_1 and Rt_0 cannot be ascribed to a momentary interruption of the treatment of S_1. Grouping therefore remains most likely at the small intervals. The fact that this generally occurs in this experiment has been explained earlier in this section as a consequence of the constancy of the interval.
Many factors may determine the subject's strategy: instruction, length and constancy of the interval, signal-complexity etc. If the instruction emphasises successive handling, this process is likely to predominate, even if grouping is normally preferred. Probably grouping is preferred at small intersignal intervals and successive handling at larger ones.

We spoke already about uncertainty of the interval in relation to selective strategy. Now, if the subject is able to use both grouping and successive treatment as selective strategies, the relation between Rt_1 and Rt_2 will be highly affected by instruction. At exp. 8 this has been shown in fact for the interval 0.0 sec. At large intervals successive treatment is expected, according to formula 2a or to 2b, which processes are supposed to be equally efficient within a certain range of intersignal intervals. In fact, Hick (1948) has considered the possibility that transmission of successive signals might be affected by instruction, but the issue is neglected in more recent studies.
A final experiment – an extension of exp. 8 – was designed to test this hypothesis.

EXPERIMENT 12

METHOD AND PROCEDURE

The same experimental set-up and task were used as in exp. 8. Twelve subjects were randomly assigned to two groups of 6 subjects each. They were tested at one fixed interval, being 0.2 sec. or 0.4 sec.
Before the experimental session the subjects were informed that in responding to two successive signals, one is able to apply different strategies, i.c. "grouping" and "successive treatment". Grouping was defined as "collecting all perceptual data before preparing any response", and successive treatment as "completing Rt_1 before taking any notice of S_2". Then an intensive training-series was given on both strategies, up to the point where the Ss. could voluntarily switch from one to another strategy. As a criterion that the Ss. could obey the instruction, the Rt_1 and Rt_2 had to be in accordance with either formula 1 or 2a. Each subject was trained at that interval, at which he would be tested during the experiment.
The experimental session consisted of two series of twenty pairs of signals. In one series the instruction was given "to group", while "successive treatment" was required in the other. Accuracy was stressed; the remaining errors were omitted from treatment and replaced by a new pair of signals. The median values of the series were used as scores.

RESULTS

The means of the median reaction times to S_1 and S_2 are presented in table 26. Moreover the mean total reaction time ($Rt_{tot} = Rt_2 + I$) is included in this table. To determine whether the subjects obeyed the instruction, the predictions about Rt_2 were calculated. The results of exp. 8 are added to enable comparison (only the values obtained at 6° display angle).

TABLE 26 - Means of median reactiontimes (in sec) as a function of intersignal interval and of instruction.

Condition (Instruction)	Interval 0.0 sec (see exp. 8)			0.2 sec			0.4 sec		
	Rt_1	Rt_2	Rt_{tot}	Rt_1	Rt_2	Rt_{tot}	Rt_1	Rt_2	Rt_{tot}
Success. treatment									
obtained	.46	.87	.87	.37	.54	.74	.44	.48	.88
predicted		.92			.54			.48	
Grouping									
obtained	.65	.72	.72	.60	.48	.68	.89	.53	.93
predicted		.65-.80			.40-.55			.49-.64	

STATISTICAL ANALYSIS

To decide upon the relative efficiency of grouping and successive treatment, the differences between Rt_{tot} were statistically tested by means of a seperate analysis of variance for each group. No significant differences appeared at $I = 0.2$ and 0.4 sec. ($F = 2.15$ and 2.47 resp. $p > 0.05$).

DISCUSSION

The results agree with the prediction. When the intersignal interval is 0.2 sec. or 0.4 sec. the subjects can behave completely according to Discr. $S_1 \rightarrow$ response $S_1 \rightarrow$ Discr. $S_2 \rightarrow$ response S_2, when they are instructed to do so. Also the "grouping" instruction delivered the predicted results. It is emphasised again that the subjects can select and transmit the information according to more than one selective strategy. It is quite probable that at the intervals 0.2 sec. and 0.4 sec. no grouping in the proper sense has occurred. Rather a process according to Discr. $S_1 \rightarrow$ storing $S_1 \rightarrow$ Discr. $S_2 \rightarrow$ response $S_1 \rightarrow$ response 2 is likely. These processes are difficult to discriminate by instruction. The reason that the latter one is thought to predominate is that in the case of real grouping, the selective act should contain both

S_1 and S_2, so that transmission of the signals could only start after 0.2 or 0.4 sec. This would imply an enormous loss of efficiency in the course of the action and the total reaction time would be much longer than when "successive treatment" was instructed. Apparently both processes are equally efficient however (see table 26), rendering grouping in the proper sense quite unlikely. Moreover it was shown in experiment 11, that grouping is no longer the preferred strategy at the interval 0.2 sec. – at least not for most subjects.
As a general conclusion of exp. 11 and 12, we may say that the present analysis of the selective processes in the "psychological refractory period" is quite in line with the analysis at the previous experiments. Evidence was obtained that the grouping process is likely to play an important role if two signals arrive successively – provided that the intersignal interval is small. The experiments have also stressed the many stimulus conditions, which exert an effect on the way the selective process takes place.

5. Summary of the chapter

The aim of this chapter was to investigate whether the decline in performance as a function of display angle – and especially the drops at the transition from stationary field to eyefield, and from eyefield to headfield – could be ascribed to a change in selective strategy. The experiments suggest that this is indeed possible. It seems likely that the three levels of the functional visual field have each a preferred selective strategy – varying from a tendency to group the two signals in one selective act in the stationary field, to pure successive treatment in successive selective acts in the headfield. To the author, the "semi-grouping" strategy in the eyefield was most interesting: here it seems that both signals are apprehended in the first selective act, albeit not completely. About S_r, only a hypothesis is obtained, which must be checked in an additional selective act.
Several predictions from this theory were confirmed. A subject is able to express a hypothesis about S_r, while S_l is fixated by the eye – as long as the signals are in the eyefield anyway – (exp. 10). Apparently the impression about S_r is less clear if the subjects are untrained (exp. 9). Explicit instruction to handle the signals successively yields a larger reaction time, than if one is instructed to group the signals (exp. 8) – which is accordingly found only in the stationary field and the eyefield. Finally, we can mention the great difficulties to shift the

eye from S_l to S_r after the completion of Rt_l – again in the stationary field and the eyefield (exp. 7). The unsatisfactory situation with respect to grouping and successive handling of signals in the framework of studies on the psychological refractory period, was the motive to experiment 11 and 12.[1]

So far the results are certainly consistent with the theory, although it is admitted that most of the evidence is indirect. It is recognized that the theory does not lend itself very easily to directly crucial experiments. One cannot have a look in man's brain and therefore most of the processes had to be based upon inference. To establish the theory in this way, a great number of falsification experiments is required. In this chapter some of these have been carried out within the frame of a rather simple reaction task.

[1] The author was assisted in these experiments by Mr. B. J. Schreurs.

CHAPTER 4

THE SELECTIVE PROCESS IN SOME VISUAL TASKS

1. Introduction

In the forthcoming chapters we shall examine how far the developed theory about the selective process can be applied to other – and more complicated – visual tasks. As was noted at the end of Chapter 3, we have been engaged on the analysis of the selective process at one circumscribed task. This was necessary in order to carry out an analysis of the microstructure of the drops in performance. Now the question must arise whether these results have some generality.

A wide field of research is opened in this way, since predictions about the selective process in many visual tasks can be formulated and preliminary interpretations of earlier experimental results can be specified. For instance, the research on noise effects on behaviour, has revealed that so called "unisource tasks" are less sensitive to noise stress than "multi-source tasks" (Jerison 1957; Jerison and Wing 1957). It has been discussed in chapter 2, that at a small display angle, a "two source" task was not hampered by noise, while it was hampered if the signals were presented at a large visual angle. The earlier interpretation was in terms of "a selective strategy which was not sensitive to noise" in opposition to "one that was sensitive". This formulation may be specified by proposing that at a small display angle, the signals are grouped, while they are treated in successive selective acts at a large display angle. The idea may be put forward that the noise can enter the transmission channel more easily if successive independent selective acts, separated by eye movements, are involved. The eye shifts may cause a momentary gap in the selective process and offer an opportunity to the noise to enter the transmission channel. With this tentative explanation, we exceed the structure of the selective process and reach the field of the dynamics of attention.

In fact, attention was necessary in all previous experiments. The subjects had to be willing to select the task stimuli and to keep up an alert attitude. In no case, however, has there been a choice element in the sense that one out of several relevant stimuli could be chosen, or that intruding irrelevant stimulation – like noise – was presented. Furthermore, the tasks never lasted longer than five or ten minutes. In the following experiments, the attention aspect will be more clearly present. Performance as a function of display angle will be measured in some tasks, where the attention element is known to be important: a visual search task, a vigilance task and finally a task with high information load.

In general, the analysis will not be as detailed as in the previous chapter. The only intention of this part of the study is to formulate some predictions about the selective process and to determine whether these are confirmed. This will be done without any claim of being exhaustive.

2. *Selective strategy in a visual search task*

The general plan of a visual search task is that a subject has to detect a visual signal – while he is uncertain about the actual spot at which this signal is present or may appear. The relevant target can be hidden between irrelevant signals or it can be presented somewhere by itself. The appearance of the signal can be announced by a warning signal, or the moment of appearance can form a second class of uncertainty. In the latter class of situation the signals may appear seldom, in which case we speak about vigilance in combination with search. This kind of situation will be dealt with in the next section of this chapter. For the moment we shall be engaged only with situations in which the subjects know "when" but not "where" the stimulus comes. The problem to be dealt with concerns the general question whether the structure of the functional visual field, as found in the previous chapters, returns in a search situation.

An example of a search task was already met in chapter 2, where the work of Corbin et al. was discussed. It will be remembered that the authors concluded to a change in selective strategy at the same display angle, where Drop II was found in our experiments. This is promising since it suggests that the theory of the sequence of selective acts has a wider field of application than within the constraints of the experimental situation that were present in our research.

However two questions remained to be answered concerning the results of Corbin et al.

First, an equivalent to Drop II was reported but not one to Drop I.

This can be explained by the fact that the task required detection instead of discrimination. We found that in the eyefield the subjects could formulate a hypothesis about S_r with success and for this reason we can assume that, if mere detection is required, the stationary field does not differentiate from the eyefield. Secondly, the deterioration of performance was found in an increase of the variance rather than of the mean of the reaction times. Beyond the critical display angle some signals were detected rather slowly, while others were found rapidly. Starting from the idea that beyond the eyefield at least two selective acts are necessary to cover the display field, this phenomenon becomes clear. When in a search situation the signal is transmitted either during the first or during the second selective act, much larger variance in response times will be found, than when only one selective act is sufficient to cover the area. The average response time, however, is not expected to differ in a dramatic way.
The question arises how the selective acts cover the display field. It may be supposed that in the first one, the whole eyefield is covered, while the second act is devoted to the remaining part of the display field. This would be in line with the general trend of the foregoing chapters. The difference between the tasks may change this picture however. For instance, one alternative hypothesis may be that both acts covers an equal part of the display field, so that the maximal spatial area, which is possible by reason of the physiological and anatomical limits, would not be covered in the first selective act.
In the forthcoming experiment this question will be considered within the context of the general problem of the succession of selective acts.

EXPERIMENT 13

METHOD AND PROCEDURE

As in all previous experiments, the subject was seated at a table at a distance of 70 cm. from a screen. Slightly above eyelevel, six columns of dots were projected in a horizontal row and so, that the distance from the subject to the outer left and right column was equal. Also the mutual distances between the columns were equal. Each column contained four dots, except one, which consisted of five items.
The diameter of a dot was 1 cm. and the same lenght accounted to the distance between two dots. They appeared as bright spots on a darkened background.
The task was to determine which of the six columns consisted of 5 dots,

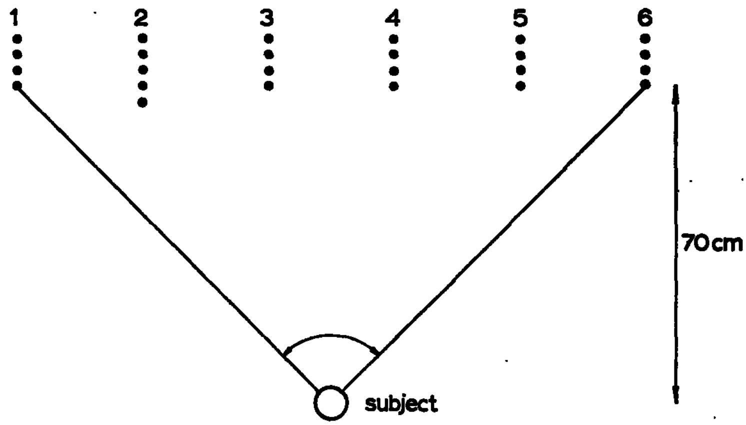


FIG. 18 - Schematic drawing of the search task

after which an appropriate key from a set of six keys – attached to the table – had to be pressed. A new presentation of the dot columns appeared 0.1 sec. after a reaction. In this way an unpaced continuous reaction task was carried out for 8 minutes. Which dot column contained five dots was randomly determined by the stimulus selector, which was also used in the previous experiments (see fig. 19). Every time, one of six projectors from the projection unit was opened.

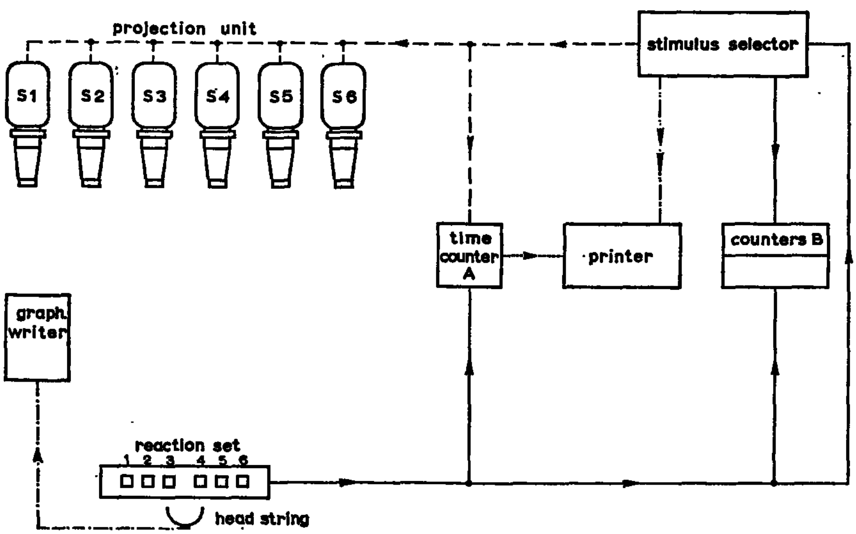


FIG. 19 - Schematic drawing of the apparatus

The slides in the projectors all contained the six dot columns, but they differed as to which dot column had five items. At the slide in projector 1, this was the exterior column to the right of the subject's position, and at projector 6 this was the extreme left. Much effort was given to equalising the patterns in all other respects, to exclude the possibility that subjects relied on other cues than the position of the five-dots column.

The total number of reactions and the number of correct responses were registered on counters (resp. A and B). Furthermore, presented signals, responses and reaction times were recorded separately on a printer. 9 Naval ratings served as subjects in the experiment. After a 10 minutes trainingperiod, they did three experimental runs with a five minutes break between two subsequent runs. The variable was the display angle, which could be 68°, 81° or 94°. Every subject was tested on all conditions; the order was counterbalanced according to a Latin Square arrangement. The subjects were instructed to work with optimal speed and accuracy. Throughout the experimental runs, head movements were measured in the same way as in the previous experiments.

As can be seen from this experimental set up, the visual search is restricted to the inspection of series of information sources. This method has two advantages above free search for signals in an empty field – with respect to our aim at least. First the spatial uncertainty is held constant when the display angle is varied, because a change in display angle merely implies an alteration of the mutual distances between the information sources. A second possible advantage can be that the search is more organised and predictable, if a fixed number of information sources must be inspected than when an empty field is scanned (White and Ford 1959). The idea is, that the sequence of selective acts will be less liable to variation in the former case and thus an interpretation of the results may be more easily obtained.

RESULTS

A preliminary analysis of the data was carried out by averaging the reaction times for each subject at each condition. Per subject a mean Rt per condition was obtained. Afterwards this was extended by the calculation of separate mean reaction times to the middle and outer signal sources (respectively 3, 4 and 1, 2, 5, 6 – see fig. 18). The data are presented in table 27 and fig. 20.

TABLE 27 - Mean reactiontime as a function of display angle

Display angle	Mean total Rt. (in sec)	Mean Rt. (middle signals)	Mean Rt. (Outer signals)	Mean $\frac{\text{Rt. outer signals}}{\text{Rt. middle signals}}$
68°	.93	.90	.95	1.05
81°	1.01	.94	1.05	1.12
94°	1.05	.97	1.09	1.13

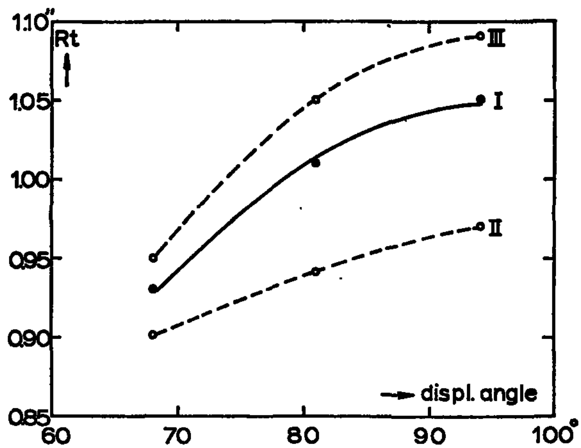


FIG. 20 - Mean reaction time as a function of display angle in a visual search task
I: Total reaction time; II: Reaction time to middle signals;
III: Reaction time to outer signals

STATISTICAL ANALYSIS

To test the statistical significance of the differences between the mean reaction time per condition, four analyses of variance were carried out, one for each set of means. In every case the mean reaction times per subject were used as cells in the analysis. A significant difference between display angles was found at the total reaction times and at the reaction times to the outer signals ($F = 37.1, p < 0.001$ and $F = 45.3$ $p < 0.001$) but not at the reaction times to the middle signals ($F = 1.83$ $p > 0.05$). As to the ratio between Rt-outer signals and middle signals, the F value just failed to reach the 5% level of significance ($F = 3.48$ $0.1 > p > 0.05$). Application of t-test showed that the significant differences between display angles are mainly due to the increase of Rt between 68° and 81°. The difference between 81° and 94° were not significant.

The records of the head movements were quite irregular, which is explained by the fact that during performance no constant visual angle was covered. It was decided to carry out only a rough analysis on the data. The records were divided into three classes (1) head movements were absent, (2) generally, small head movements were made – less than 15°, and (3) generally, large head movements took place (more than 15°). The results, obtained in this way are given in table 28.

TABLE 28 - Head movements as a function of display angle

	Display angle		
	68°	81°	94°
No head movements	7	0	0
Small head movements	2	3	1
Large head movements	–	6	8

In commenting upon these results, it can be said that, also in this experimental situation, there is evidence for a drop in performance if the eyefield is exceeded. The stronger increase in Rt between 68° and 81° than between 81° and 94° clearly points into this direction. The results are different from the previous data, sofar that the drop and also the head movements tend to occur at a smaller display angle. It seems reasonable to suppose that this finding is effected by the greater complexity of the task. It is quite plausible, that the present task is more difficult than the one used previously. Starting from the idea that within the eyefield, hypotheses about the signals can be formulated, it is likely that with an increased number of signals – being presented simultaneously – such hypotheses become impossible at a smaller display angle.

A further finding concerns the fact that only the outer signals show the drop in efficiency and not the middle ones. This can also be explained on the basis of the all or none possibility to formulate the hypotheses. Where ever the eye fixation takes place at the arrival of the signals, the middle signals will always tend to be within the eyefield, which cannot be said of the outer signals.

The treatment of the data does not allow a further analysis of the selective process. The main difficulty is, that during an experimental run no constant visual angle was covered. If signal 1 is followed by signal 6, this angle is different from that when signal 1 is followed by signals 2 or 3. It is possible, however, to calculate the objective visual angle between every sequence of signals. They are listed per display angle in table 29.

TABLE 29 - Visual angle between two successive signals (within rounding error)

		Signal I																	
		1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Signal II	1	0	12	26	42	56	68	0	14	30	50	67	81	0	14	35	59	80	94
	2		0	14	30	44	56		0	17	37	54	67		0	21	45	66	80
	3			0	16	30	42			0	20	37	50			0	24	45	59
	4				0	14	26				0	17	30				0	21	35
	5					0	12					0	13					0	14
	6						0						0						0
		Total display angle: 68°						Total display angle: 81°						Total display angle: 94°					

Now it is possible to calculate the mean reaction time per subject as a function of the visual angle, which is covered in two successive signals. From the values per subject a general relation between reaction time and visual angle can be obtained.

In doing so, we should recognize however the tacit assumption that the eye remains at the place where a five dot column was present until the next presentation has arrived. If this is not true, the analysis of the data in terms of the objective visual angle to be covered in each succession will be of little value. As a check whether in fact the subject starts to inspect that signal, to which the last response has been made, the results should indicate that the reaction times are considerably shorter if in two successive presentations the 5 dot columns are at the same signal source. Before any other interpretation of the results, this should be considered in the discussion.

In the construction of the function, equal or nearly equal visual angles were combined. For instance, the reaction time after a shift from column 1 to column 4 and from column 4 to column 1 were taken together. This was done to obtain sufficiently large samples of reaction times per subject for each visual angle. It is recognized that this treatment leads to a loss of information: so it is probable that shifting from left to right is carried out more efficiently than from right to left (v. d. Meer 1958). For the moment such factors had to be neglected, however.

The results of this treatment are found in table 30 and fig. 21.

TABLE 30 - Mean reactiontime as a function of visual angle

Display angle: visual angle	68° Rt	Display angle: visual angle	81° Rt	Display angle: visual angle	94° Rt
0°	.69	0°	.68	0°	.65
12°-16°	.89	13°-17°	.91	14°	.90
26°-30°	.96	20°	.90	21°-24°	.95
42°-44°	1.03	30°	.97	35°	1.04
56°	1.11	37°	1.12	45°	1.18
68°	1.15	50°-54°	1.21	59°-66°	1.29
		67°	1.28	80°	1.36
		81°	1.27	94°	1.37

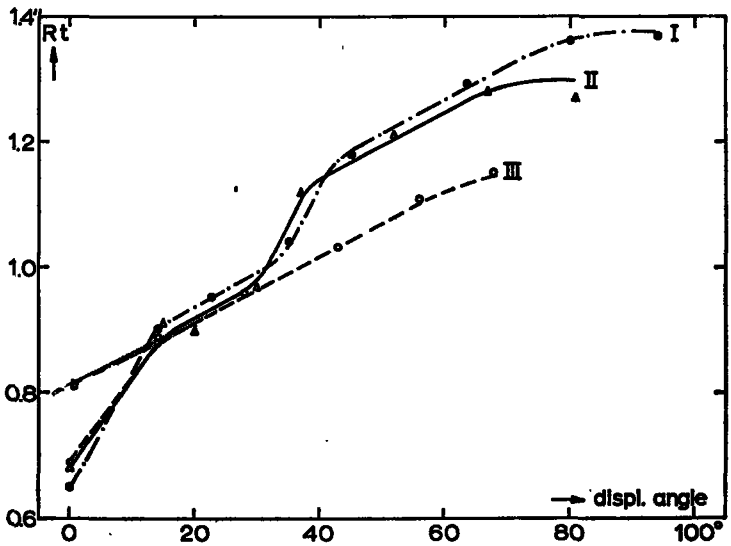


FIG. 21 - Mean reaction time as a function of visual angle to be covered in successive signals
I: Total display angle 94°; II: idem 81°; III: idem 68°

STATISTICAL TREATMENT

It was a difficult matter to test the differences between the visual angles within this experimental design. Calculation of separate analyses of variance seemed the best approach. For each display angle this treatment was carried out with the mean reaction times per subject as cells. The results are summarised below.

TABLE 31 - F-values and confidence limits between visual angles

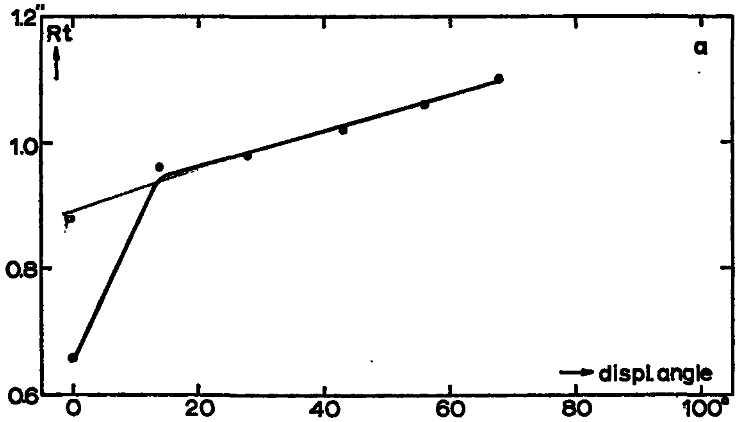
Display angle	F-values between visual angles	Confidence limits (t-test)
68°	26.55 $p < 0.001$	5%: > .09 1%: > .12
81°	24.3 $p < 0.001$	5%: > .11 1%: > .14
94°	55.7 $p < 0.001$	5%: > .09 1%: > .12

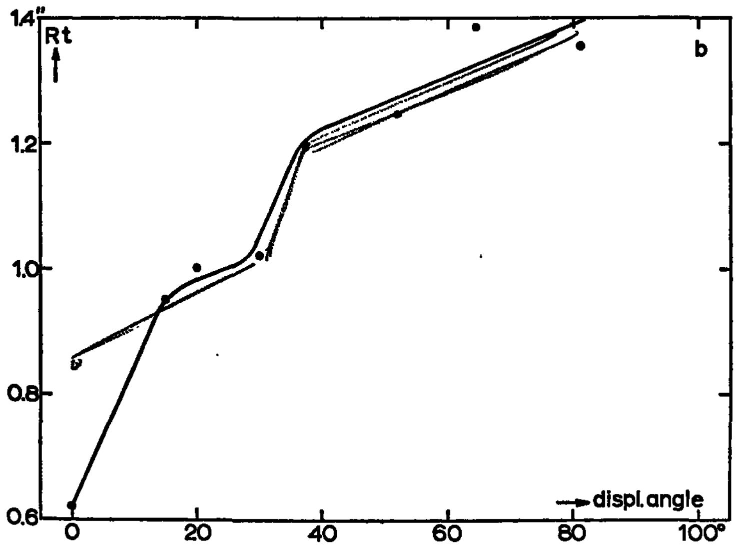
Furthermore, mean reaction times per subject of comparable visual angles from each display angle were taken as cells in the original Latin Square arrangement. No difference between display angles appeared at visual angles of 0°; 12-17° and 20°-30°. However, if the visual angles of 59°-68° are compared, a significant difference between display angles appears ($F = 7.84$, $p < 0.01$. Confidence limits: 5%: .08; 1%: .11).

As is suggested by fig. 21 the course of the curves coincides till about 35°. Then they diverge, in the sense that at display angle 68° the linear trend is continued, while at display angles 81° and 94° an increase in reaction time occurs, followed by a new linear trend, running parallel with that found at 68°.
Before commenting on these results, we shall report the data of a control experiment in order to crossvalidate the data. Instead of a Latin square arrangment, separate groups of subjects were only tested on one condition. 20 subjects – all naval ratings – served as subjects. Nine were tested at 68° display angle, five at 81° and six at 94°. The results were treated as in the main experiment and are given in table 32 and fig. 22.

TABLE 32 - Mean Rt. as a function of visual angle in a contineous search task

Visual angle	Rt Display angle 68°	Visual angle	Rt Display angle 81°	Visual angle	Rt Display angle 94°
0°	.66	0°	.62	0°	.66
12°-16°	.96	13°-17°	.95	14°	.94
26°-30°	.98	20°	1.00	21°-24°	1.05
42°-44°	1.03	30°	1.02	35°	1.12
56°	1.06	37°	1.20	45°	1.36
68°	1.10	50°-54°	1.25	59°-66°	1.43
		67°	1.39	80°	1.48
		81°	1.36	94°	1.49


1.2"
Rt
a
1.0
0.8
0.6
displ. angle
0
20
40
60
80
100°


1.4"
Rt
b
1.2
1.0
0.8
0.6
displ. angle
0
20
40
60
80
100°

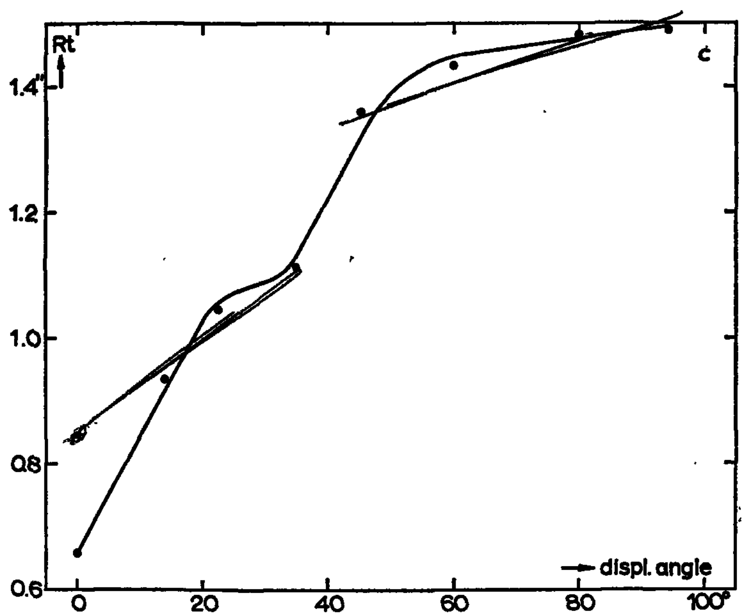


FIG. 22 - Mean reaction time as a function of visual angle to be covered in successive signals. (compare fig. 21)
a: Total display angle 68°; b: idem 81°; c: idem 94°

STATISTICAL ANALYSIS

With the individual mean reaction times as cells, three analyses of variance were carried out; one for each set of data. The results are summarised below.

TABLE 33 - F-values and confidence limits between visual angles

Display angle	F-values (between visual angle)	Confidence limits (t-test)
68°	30.3 $p < 0.001$	5%: > .08 1%: > .11
81°	44.6 $p < 0.001$	5%: > .11 1%: > .14
94°	36.3 $p < 0.001$	5%: > .14 1%: > .19

The results of the control experiment are largely equal to those obtained in the main experiment. After a strong increase of reaction time between 0° and 12°, the course has an apparently linear increasing trend at 68°. At 81° and 94°, again a significant drop in efficiency occurs at about 35°.

The results support the idea that at a new presentation, the subject starts to inspect that dot column which contained five items in the previous presentation. As was pointed out, this is a necessary prerequisite if we want to discuss the results in terms of angular distances between subsequent signals. Since the mean reaction time is considerably shorter when equal signals succeed each other, we have some reason to suppose that the objective visual angle between successive signals is in agreement with the angular distance that is covered by the eye.

Taking this for granted, the most striking feature of the results is, that the course of reaction time as a function of visual angle shows a fundamental change, when the display angle exceeds the eyefield. The curves coincide until 35° approx., after which a drop in performance appears, when the display angle is 81° or 94°. It can be said in fact, that the increase in average reaction time as a function of display angle (see fig. 20) is mainly due to reactions upon those signals which had a larger angular separation than 35° from the previous one. As long as the total display angle is within the eyefield – which is the case at 68° according to the head movement measurements – the reaction times follow a strictly linear course.

According to the theory that within the eyefield hypotheses about signals can be formulated, we would expect a linear function, indeed. The place of the 5 dot column is supposed to be rapidly detected – being relatively independent of the angular separation. A certain increase of the mean reaction time should occur however, if the visual angle increases, for the mere reason that larger eyeshifts are required from the fixation point to the five-dots pattern. These eyeshifts are necessary in order to check the hypotheses.

This explanation assumes in fact, that, within the eyefield, the proper search plays only a secondary role. With a hypothesis as to where the 5 dot column can be found, a straight eyeshift to that signalsource is predicted. A direct proof of this idea cannot be given since no eye movements were measured. There is some indirect evidence by reference to the increase of eye movement time as a function of visual angle. If the data of table 30 and 32 are corrected for movement time, the bigger part of the increase of Rt disappears at the linear parts of the functions (see fig. 23). The remainder may be due to a perhaps more imperfect and slower hypothesis formation at large angular separations in the eyefield. The latter factor can be considered as a minor one however – in the present experiment at least. (see chapter 5).

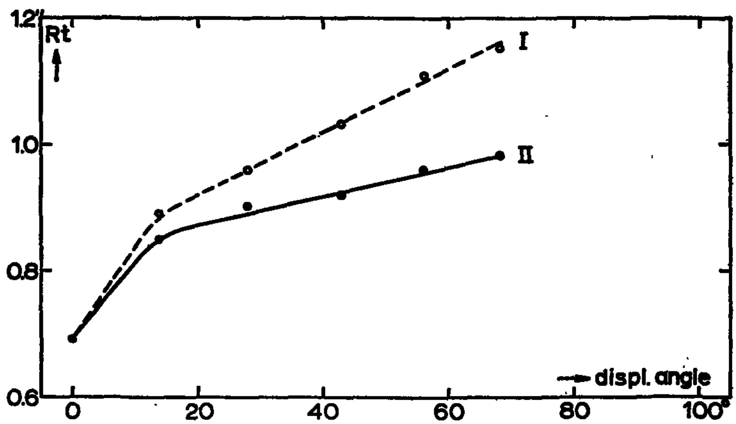


FIG. 23 - The effect of movement time on the slope of fig. 21; III
I: Reaction time according to fig. 21; III
II: Reaction time after subtraction of movement time

Beyond the eyefield, reaction time will rise again, since two successive selective acts are required to cover the display. The striking feature of the results is, that the drop does not occur at the limits of the eyefield, but already at 35° approximately. So, in fact, during the first selective act, many less hypotheses about the dot columns are formulated than was the case when the whole display angle was within the eyefield. Instead of covering the whole eyefield in one selective act and the remainder in the next one, the displayfield seems to be split into two parts. In the first act only 35° is covered, while the remainder must await the next intake of information. Thus, in the first act much less is sampled than is physiologically possible.
Inspection of table 29 – 31 shows that in principle only the column right and left from the fixated one are considered. Only if a marginal source is fixated, two adjacent dot columns are enclosed in the first act and, if the middle sources are fixated, one of the marginal sources is viewed. The remaining part of the eyefield is neglected in the first selective act. The phenomenon occurs equally whether the total display angle is 81° or 94°.
In conclusion, it can be said that the results of this experiment fit

the theory of the course of the selective process beautifully. Moreover, a clear attentional factor has been traced in the preference of the subjects to neglect information in the first selective act, when the total display angle is beyond the eyefield. These findings suggest that the theory of the levels of the functional visual field and the accompanying selective processes are more generally applicable than merely to the narrow experimental scheme that was used in the previous chapters. In the next paragraph we will consider how far the theory also holds in a watchkeeping situation.

3. Display angle and performance in a vigilance task

In the field of vigilance we meet an important phenomenon in relation to the functional visual field, that is known in the literature as "peripheral blindness" or "funnelling of attention". As was pointed out briefly in chapter 1, the terms refer to the finding that, if a subject is looking for signals that may appear anywhere on a screen in a watchkeeping situation, peripherally exposed signals are more likely to be missed than centrally presented signals. This effect tends to be more outstanding when the watch has continued for some time (Drew 1940) and, therefore, it has been suggested to apply the funnelling effect as a criterion for fatigue (Bartlett 1953).

There are indications that the effect has motivational determinants; when a monotonous task goes on, the selective strategy tends to change in such a way that extreme parts of the screen are more and more neglected. Thus, Bursill (1958) carried out an experiment in which subjects responded to peripheral signals concurrently with a continuous pursuit meter task, which was centrally located. In this study also the percentage of missed peripheral signals increased as a function of time and moreover it proved to be dependent on the load of the central task. Heat and humidity during the task increased the effect, in the sense that it occurred more rapidly than in normal environmental conditions. Also Baker (1958) has found the funnelling effect; he showed however, that it is possible to overcome the effect by biasing attention. When a box sweep line was inserted in the display, the peripheral signals were detected even better than those that were presented centrally. Finally, the phenomenon is also reported in an experiment, where eyemovements were measured during performance (Michon and Kirk 1962). At the end of the workspell, eye fixations in the periphery of the screen occurred significantly less than in the beginning.

An experiment by Broadbent (1950) casts some doubt however on the generality of the phenomenon. In a dial watching task, a series of twenty steam gauges had to be monitored at the same time. In this experiment the occurrence of peripheral blindness appeared to be dependent on the intersignal interval. Only if two signals were given shortly after each other was the reaction time to the centrally located dials shorter. In the case of long times between subsequent signals a reversed effect was noticed; then the peripheral reaction times, tended to become shorter than the central ones.
This divergence from the normal findings might be ascribed ad hoc to the fact that signal sources were inspected, so that the spatial uncertainty was less in comparison with the situation where a target can appear anywhere on a screen. But Lincoln and Averbach (1956) also used signal sources and they found the funnelling effect in the normal way. Another possibility is that the appearance of the funnelling effect is related to the extent of the display angle. In general, the displays in vigilance tasks are not very extended and can be supposed not to exceed the eyefield. In Broadbent's experiment however, the dials were placed in three rows, according to fig. 24 and accordingly the eyefield was clearly exceeded.
It can be suggested that in this case the funnelling phenomenon will tend to change. The following reasoning may be offered to outline the

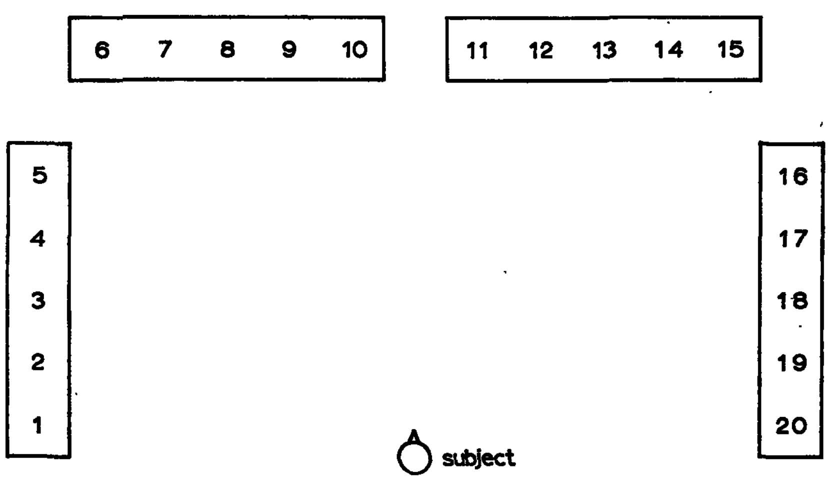


FIG. 24 - Schematic drawing of the twenty dials test (after Broadbent 1950)

hypothesis. Our theory holds that within the eyefield the whole display can be viewed in one main selective act. The peripheral blindness, then, can be interpreted as the diminished use that is made of the peripheral hypotheses as to whether or not a signal is present. It is assumed that in vigilance tasks the subjects have a selective mainpoint – defined as the area where most eyefixations take place and which must therefore be supposed to be viewed most intensively – which is located in the central part of the display, although it may be biased by the insertion of moving reference lines. This accounts primarily for the situation in the eyefield. Hypotheses about the situation in the periphery of the screen are continually present. When the peripheral information is inadequately transmitted, the peripheral signals will be missed. Consequently the check movements of the eye will disappear, so that the movement pattern will become more rigidly bound to the central part of the displayfield.

According to this theory the situation will change fundamentally, when the display area exceeds the eyefield and when – consequently – more selective acts are necessary to cover the display. In such situations we cannot speak about one selective mainpoint in the central part of the screen but instead, we may suppose the occurrence of two selective mainpoints – both in the periphery.

This tentative hypothesis is illustrated schematically in fig. 25.

So, in the headfield, the funnelling phenomenon is hardly to be expected on the basis of this theory. We may rather predict a decrease in

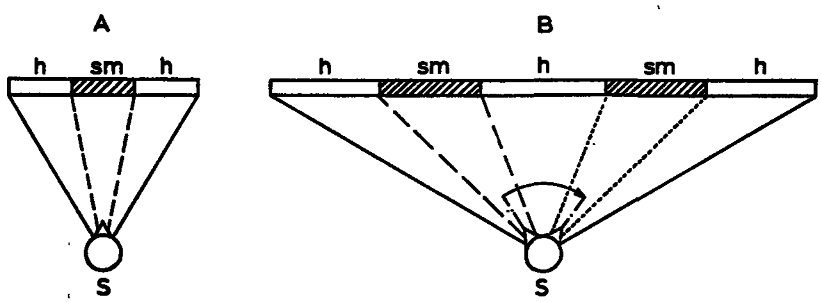


FIG. 25 - Hypothetical scheme of the selective process

A: One selective act is sufficient to cover the display field. (within the eyefield)

B: Two selective acts are necessary to cover the display field. (beyond the eyefield)

Sm: Selective mainpoint

h: Area, where peripherally obtained hypotheses are obtained

performance at the centrally located signals, since the latter have become more dependent upon peripheral viewing.
The extension of the theory to vigilance situations and the funnelling phenomenon introduces a large number of questions, which should be answered by experiment. It may be asked for instance, which effects of decrement will be likely to occur in the headfield instead of the funnelling phenomenon. It seems plausible to suppose that, when the display angle exceeds the eyefield, the task has become more stressing so that phenomena of deterioration will be evoked more easily than when the display angle is smaller. Other questions concern the regularity with which the shift from one mainpoint to theother is carried out, the relative preference of left and right etc.
The basic prediction of the theory, however, is that in the headfield, the centrally located signals will be less rapidly seen than when the total display is within the eyefield. Another prediction can be made about the variance of the reaction times. Within the eyefield, we expect a small variance for the central signals and a larger one for the outer signals. Beyond the eyefield the variance in the central signals should increase considerably, since they are supposed to be outside the focus of the selective main point. The variance in the outer signals may decrease somewhat, although not strikingly since only one group of outer signals can be taken in a selective act. When the general variance per group is calculated, an overall increase of this statistic is likely to occur in the headfield.
The following experiment is meant as a contribution to the experimental research in this area.

EXPERIMENT 14

METHOD AND PROCEDURE

A series of 16 lights was fastened to a metal rail, that was placed horizontally and slightly above the subject's eyelevel. The lights were divided into three groups: one contained eight lights, which were placed in front of the subjects – forming the central group. The other groups contained four lights each and they were located at equal distances from the central group and thus from the subject's meridian (see fig. 26).
The subject was seated at a table on an adjustable chair, at a distance of 70 cm. from the lights. All lights had equal brightness, but incidentally the brightness of one light decreased considerably. The decrease

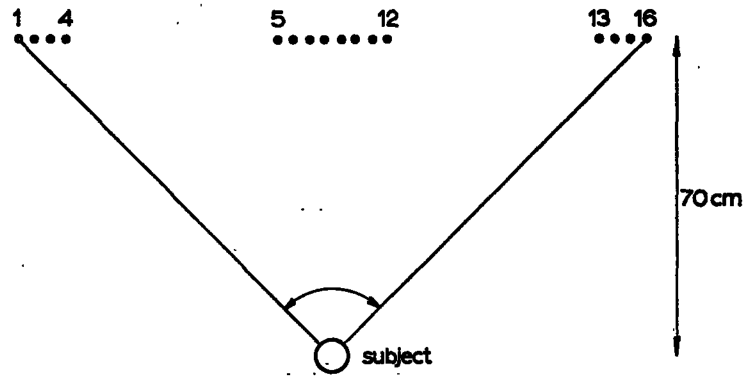


FIG. 26 - Schematic drawing of the vigilance task

served as a signal, which had to be detected by the subject. Reaction was registered by pressing a morse key, which was mounted on the table behind which the subject was seated. During the workspell head movements were measured in the usual way. The subject was told that he was free to move his head and that the string only served to keep his distance to the lights constant – which was, in fact achieved in this way.

The work period lasted one hour and in this time 32 signals were presented with irregular mutual time intervals. Each light decreased twice in brightness, according to the schema of table 34.

The presentation of the signals, the reaction time counter (hundredth of seconds) and the head movements recorder were all placed in an

TABLE 34 - Presentation scheme of the signals in the vigilance task. The numbers of the signals are in accordance with fig. 26

Time at work		Number of signal	Time at work		Number of signal
2′	32′	5	18′	48′	1
3′	33′	15	20′	50′	10
7′	37′	3	21′	51′	4
8′	38′	16	25′	55′	14
12′	42′	7	26′	56′	8
13′	43′	2	27′	57′	6
14′	44′	9	29′	59′	12
15′	45′	11	30′	60′	13

adjacent room, so that the subject was alone during his task. This was done to avoid the motivational effect of the experimenter's presence in the same room (Fraser, 1953). During performance the subject's watch and cigarettes were taken from him.
12 Naval ratings served as subjects. They were tested three times on different days under different display angles, namely 83°, 94° and 104°. The change in display angle was obtained by shifting the outer groups of signals. The central group of lights remained at the same place throughout the conditions. The order of testing was according to a Latin Square arrangement. Before testing, the subjects were acquainted with the task and were instructed to be alert and to react immediately after a decrease in brightness was detected. Since the decrease was substantial, false responses were rare and they are neglected in the treatment of the results.

RESULTS

Data were obtained on differences between display angles, between subjects, between half hour periods and between light positions (central or outer). The mean reaction times are summarised in table 35 and fig. 27.

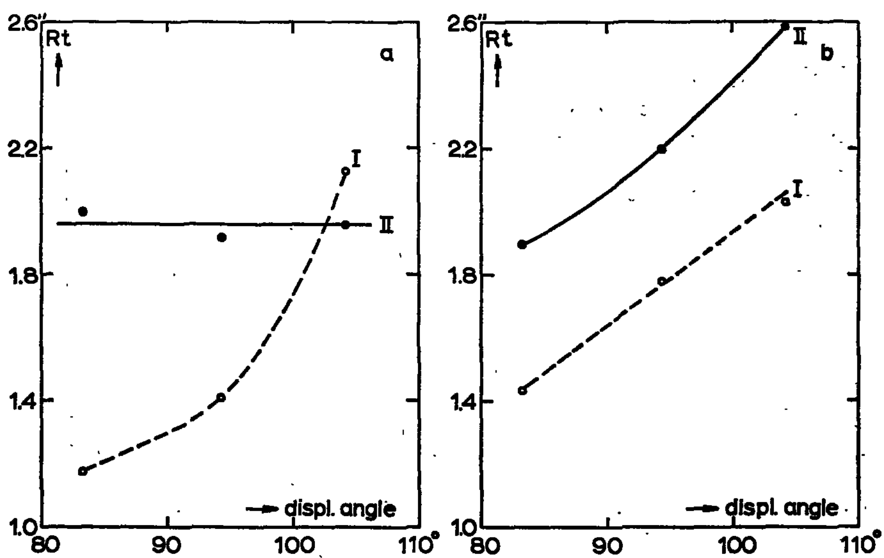


FIG. - 27 Reaction time as a function of display angle in the vigilance task
a: First half hour; b: Second half hour
I: Central lights; II: Outer lights

TABLE 35 - Mean reaction times in sec. for half hours, light positions and display angles

	Rt (total)	Rt (1th half hour) Rt (central lights)	Rt (outer lights)	Rt (2th half hour) Rt (central lights)	Rt (outer lights)
83°	1.63	1.18	2.00	1.44	1.90
display 94°	1.82	1.41	1.92	1.78	2.19
angle 104°	2.18	2.13	1.96	2.03	2.60

STATISTICAL ANALYSIS

An analysis of variance was carried out to test the statistical significance of the difference in means after a square root transformation of the data. The summary is presented in table 36.

TABLE 36 - Summary of the analysis of variance of the mean reactiontimes in the vigilance experiment

Factor	Sum of squares	Df	Mean Squares	F-value	
Order of presentation	3.05040	2	1.52520	< 1.00	
Residual between Ss	30.66500	9	3.40722		
Total between subjects (E)	33.71540	11			
Between trials (A)	0.86650	2	0.43325	1.58	N.S.
Between display angles (B)	7.02946	2	3.51473	3.15	N.S.
Between half hours (C)	2.20028	1	2.20028	1.97	N.S.
Between lightpositions (D)	6.25834	1	6.25834	5.61	N.S.
A × C	0.80020	2	0.40010	1.46	N.S.
A × D	0.27413	2	0.13706	< 1.00	N.S.
B × C	0.42655	2	0.21327	< 1.00	N.S.
B × D	0.77112	2	0.38556	< 1.00	N.S.
C × D	0.08702	1	0.08702	< 1.00	N.S.
C × E	6.09729	11	0.55430	2.02	p < 0.05
D × E	6.83646	11	0.62149	2.27	p < 0.05
B × C × D	2.23266	2	1.11633	4.08	p < 0.05
A × C × D	0.18003	2	0.09001	< 1.00	N.S.
C × D × E	4.85161	11	0.44105	1.61	N.S.
Residual Latin Square	0.42146	2	0.21073	< 1.00	N.S.
Residual within Subjects	21.35469	78	0.27378		
Total within subjects	60.68780	132			
Total variance	94.40320	143			

It appears that the interaction between display angles, half hour periods and light positions is significant. A further conclusion can be that the subjects differ in respect to reaction time in the half hour periods and at the light position (C × E; D × E).

Apart from the mean reaction times, the variance in reaction times per half hour period was determined. The result of this calculation is shown in table 37 and fig. 28.

TABLE 37 - Variance of reaction times of half hour periods in the vigilance experiment

Display angle	1th half hour	2th half hour	mean variance of (1th + 2th) half hour
83°	2.05	1.55	1.80
94°	1.60	1.84	1.72
104°	2.55	3.45	3.00

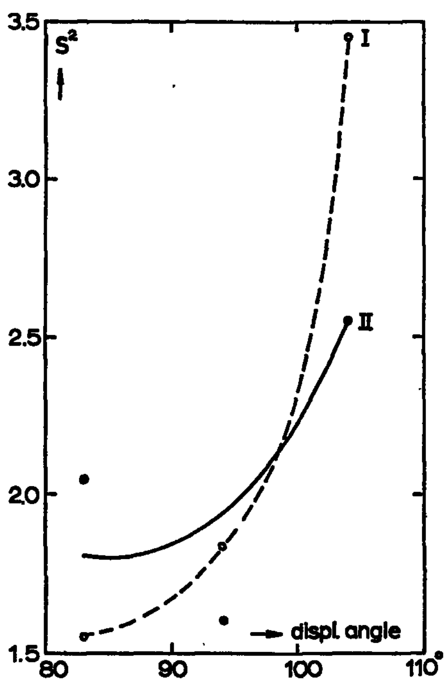


FIG. 28 - Variance of reaction times as a function of display angle
I: second half hour; II: first half hour

With the application of a similar analysis as of the reaction time data, a significant difference in variance was found between display angles ($F = 4.45$, $p < 0.05$), but not between half hour periods. Also the interaction Display angles x Half hour periods was not significant. ($F = 1.29$, $p > 0.05$). The apparent increase in variance from the first to the second half hour at 104° must be considered as due to random variation therefore.

The analysis can be refined by calculation of separate variance measures for the central and the outer signals, over the half hour periods. The results of this treatment are shown in table 38.

TABLE 38 - Mean variance for central and outer signals in the first and second half hour of the workperiod

Display angle	Central signals		Outer signals	
	1st half hour	2th half hour	1st half hour	2th half hour
83°	.73	.85	2.98	1.99
94°	.97	1.57	2.38	2.11
104°	3.80	2.50	1.25	3.47

STATISTICAL ANALYSIS

Separate analyses of variance were carried out on the columns of table 38. A significant result was obtained only at the first half hour for the central lights ($F = 4.05$, $p < 0.05$). The other differences between the means did not reach significance.

As a final calculation, the ratio of the variances of the first and second half hour per subject was determined – separately for the central lights and for the outer lights. This ratio (S^2 second half hour: S^2 first half hour) indicates the increase of variance. The mean ratios are presented in table 39.

TABLE 39 - Mean (S^2, 2th half hour: S^2, first half hour) for central and outer signals as a function of display angle

Display angle	Outer signals	Central signals
83°	1.50	1.75
94°	1.32	1.78
104°	3.34	1.30

Using the individual ratios as cells in the Latin Square, two analyses of variance were carried out after a square root transformation of the data. A significant difference between display angles appeared at the outer signals ($F = 5.45$, $p < 0.05$). No evidence was found for a similar effect at the central signals.

As in the previous experiment, the head movements were classified in three groups. 1. no head movements; 2. small head movements; 3. large head movements (more than 15°). The results are shown in table 40.

TABLE 40 - Increase of head movements as a function of display angle

Display angle	No head movements	Small head movements	Large head movements
83°	8	4	—
94°	4	7	1
104°	—	6	6

DISCUSSION

The head movement measurements show that in this task the headfield is probably reached between 94° and 104°, since large head movements tend to occur only at the latter display angle. Apparently the eyefield is extended farther in this task than in those used earlier. This is not very surprising because the present task requires mere detection of a considerable decrease in brightness, instead of discrimination of number.

It was predicted that in the headfield the reaction time to the central signals should be relatively large. In the eyefield the reaction times to the outer signals should be relatively long, while no differences between outer and central signals would exist in the headfield. The data of table 35 suggest that this prediction is confirmed, when we restrict the analysis to the first half hour of work. It seems indeed that the selective mainpoint changes when the display angle exceeds the eyefield in the sense that the central lights are viewed less – probably in favour of the outer lights. This is in agreement with the hypothetical scheme of the selective process in fig. 25 (see page 124). The finding is also in line with the result of experiment 13. Also the predictions about the variance of the reaction times are generally confirmed.

Especially the increase of variance for the central lights is striking (table 38). At 104°, the general variance was also larger than at the smaller display angles.
In the second half hour of work the results at 104° change considerably. It is clear from fig. 27 that the mean reaction times now follow the same trace as those at 83° and 94°. Apparently the inspection strategy at 104° has changed after the first half hour in such a way that the outer signals received relatively less attention. One possible explanation for this finding can be that the continuous shifts of attention are difficult to maintain throughout the whole test session. It is plausible to suppose that this process puts a considerable extra load on the task and from this it can be deduced that a loss of motivation to maintain an alert attitude will occur more rapidly.
A decrease of motivation may be outlined as follows for the present situation. If we assume a fairly regular and frequent shifting process from left to right and back again in the beginning of the workspell, it is reasonable that an outer signal can be always selected after a short time. We may suppose that the frequency and the regularity of shift decrease together with motivation. The latter assumption is in line with the blocking theory, as discussed in chapter 1. If the selective filter is satiated by the selection of the same kind of information, the intake of relevant material will be blocked from time to time. This, already, will be enough to diminish the regularity of the shifting process, as time goes on in the vigilance task. A consequence of the irregular shifts is, that the chance of remaining undetected for some time increases proportionally for an outer signal. This will be seen in both the reaction time and the variance of the outer signals. For the central signals no considerable changes are expected since they are supposed to be present in the periphery, whether the selective mainpoint is to the right or to the left. From the results both deductions are confirmed. Especially the increase in variance of the outer signals in the second halfhour period is striking (table 39), while such signs are absent in the variance of the central signals.
A test of the theory could be in the analysis of eye- and head movement records. This accounts both for the idea of a double selective mainpoint in the headfield and for the increasing irregularity as a function of time. Both must await further research however, since in the present set up eye movements could not be registered for longer times and the analysis of the regularity of head movements was impossible, since only short samples had been collected. So far however, the results on

reaction times are in agreement with the theoretical predictions and although this cannot be considered as an ultimate proof according to methodological standards, it should be accepted as positive evidence.

A final point to be made concerns the fact that only at the display angle of 104° phenomena of deterioration could be traced. As known from the work on vigilance – Broadbent (1958) – we would expect an increase in variance in view of the fact that we used an unpaced vigilance task. Now, at 104° the variance measurements tends to rise considerably, while they remain nearly equal at 83° and 94°. This finding agrees with the idea that a task is fundamentally easier and less "fatiguing" if the display angle does not exceed the eyefield.

Summarising, it may be said that new evidence has been obtained for the idea that outside the eyefield a new selective strategy is used. Two selective acts are likely to occur in order to carry out one inspection of the display field. It is an important addition that the latter process proved to be more difficult and fatiguing than the process in the eyefield.

Several questions remain to be cleared up however. For instance, the application of the theory to the funnelling effect remains entirely in the hypothetical sphere. This experiment was in fact less apt to deal with the funneling phenomenon in itself, since the signals were presented from fixed information sources. Nevertheless, the data from the literature on funnelling fit our theory.

4. Display angle and performance in a memorizing task

In chapter 1, the old datum of experimental psychology has been mentioned that the immediate memory capacity is maximally about some six or seven units, which number can be substantially extended by the presentation of meaningful material (e.g. Wundt 1896). Recent research in this field has continually stressed the importance of sequential redundancy with respect to the actual number of letters or digits that can be apprehended. The idea is that, if the material is meaningful and organised in some way, the message units are recoded in new and more extended units. The total of the new units equalises again the six or seven items (Miller and Selfridge 1950; Smith and Miller (1952).

In chapter 1, we have discussed the question of how far successively presented units can be actually integrated into larger units. Especially the work of Cherry and Taylor (1954) and of Michon (1962) was important in this respect and it was concluded that each bit of speech – or group of letters – should have some inner structure in itself, in order to make the recoding process possible. Now this question will be considered in relation to the structure of the functional visual field.

In *memorizing* experiments in which simultaneous visual presentation is used, the material has been generally presented within the area of the eyefield. According to our theory one main selective act should have been sufficient, therefore, to sample the information – at any rate *if the total amount is within the limits of the channel capacity* and the immediate memory system. What will happen however, if the spatial intervals between the message units are so large that the display angle exceeds the eyefield? According to the theory, two selective acts should be necessary and the problem is how far sequential redundancy will still be recognized under the latter circumstances.

The following experiments were carried out to shed light upon this question.

EXPERIMENT 15

METHOD AND PROCEDURE

The experiment took the form of a study on memory span. A number of signs were presented visually and simultaneously in a horizontal row at about eye level. The experiment was carried out in a dark room and the signs were projected on a screen with a figure-to-background brightness that was far above threshold. As in the previous studies, the subjects were seated at a distance of 70 cm. from the screen on an adjustable chair. The head was placed in a string to keep this distance constant and in order to measure head movements in the usual way.

The signs consisted of plus (+) and minus (—) marks, with a length and a width of 1 cm. The mutual distances between the signs were equal. The presentation lasted 1 second, after which the subject had to write down the signs in the correct order on a test form. Three experimental variables were introduced in the experiment.

a. The number of signs: in some conditions 6 signs were presented and in other conditions 8 signs. These numbers were chosen intentionally. It can be expected that 6 signs are still within the memory span, while 8 signs will be beyond the threshold.

b. The display angle: the angle that was formed between the extreme signs and the subject could be 9°, 32°, 52°, 71° or 90°.

c. The sequential redundancy: either a sequence of signs was randomly constructed – with elimination of the casual "easy sequences" – or only the first half of the sequence was randomly determined, while the second half was an exact repetition of the first half.

The experiment had a factorial design. Owing to the variables there were 20 experimental conditions. To each condition, a separate group of 5 subjects was assigned, sothat in total a hundred individuals – naval ratings – served as subjects. Thus, each subject was tested on one condition only. During the experiment, he got four different series of signs. The composition of the series was kept constant at the various display angles. Before the experiment started, the subject was acquainted with the task. A preliminary series of signs was presented with a display angle, which was equal to which he would be subjected.

Every sign that was reproduced in the correct place in the sequence, was considered as a correct response; all the others as errors. In the case of a series of 6 signs, the subjects could have 24 errors maximally, while at 8 signs, 32 errors were possible. To make both conditions comparable, the number of errors was expressed in terms of percentages.

RESULTS

The mean percentages of errors are given in table 41 and fig. 29.

TABLE 41 - Mean percentages of errors in the reproduction of signs as a function of display angles

Number of signs	Display angle				
	9°	32°	52°	71°	90°
6 redundant	7.4	8.8	14.8	17.2	33.4
6 random	9.8	11.6	14.8	21.0	40.8
8 redundant	3.0	10.0	15.8	28.8	38.4
8 random	39.6	39.3	33.8	39.0	35.2

STATISTICAL TREATMENT

An analysis of variance was carried out on the data, which showed a significant interaction effect of number of signs, redundancy and display angles. ($F = 4.08$, $p < 0.01$). Application of t-test showed that a difference of 12.5% was necessary between two conditions in order to reach the 5% level of significance.

So, no significant differences existed between degree of redundancy, if the number of signs was six, but a very marked effect appeared when

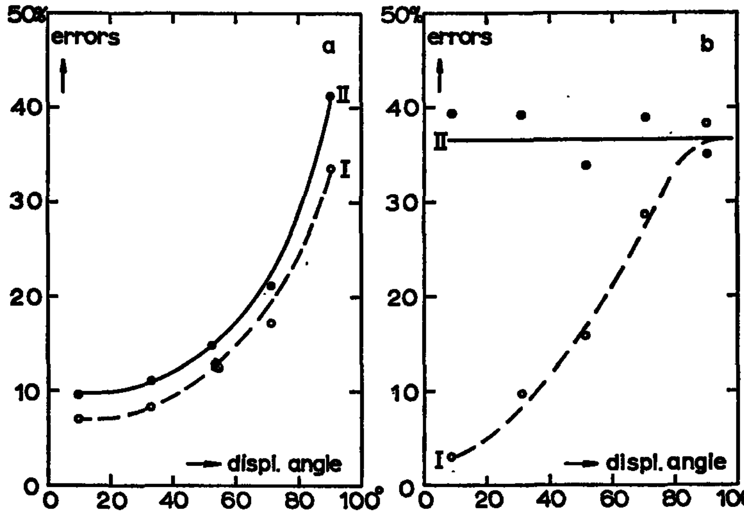


FIG. 29 - Percentage of errors as a function of display angle in a memorizing task
a: 6 signs per presentation; b. 8 signs per presentation
I. symmetrical composition; II. random composition

the number of signs was 8; this with the restriction that the difference ceased at the larger display angles.

Between display angles, the error percentages tend to increase slowly up to 70°, after which the errors rise sharply. The difference between 9° and 70° is still within the random error if six signs are presented. At 8 signs, the increase is more pronounced from 52°, if the material is redundant (see chapter 5). Non-redundant material is reproduced badly at all display angles.

Measurement of head movements showed that only a few head movements were made during the showing of the signs. In view of the big individual differences in making head movements these data were considered as unreliable however. A new experiment was carried out therefore in order to confirm this impression. 8 subjects got each two series of signs (8, non redundant) at all display angles, the order being counterbalanced in a Latin Square design. The error percentages proved to be similar to those obtained in the main experiment (40% approx., undependent of display angle). The mean degrees of head movements are given in table 42 and fig. 30.

The statistical analysis was carried out after a $\sqrt{x + 0.5}$ transformation of the data. The differences between display angles did not reach the 5% level of significance. ($F = 3.17$; $0.05 < p < 0.10$).

TABLE 42 - Mean degree of head movements during inspection of the signs (8, not redundant) at various display angles

Display angle	32°	52°	71°	90°
Mean degrees of head movements	1.0°	2.0°	7.4°	6.5°

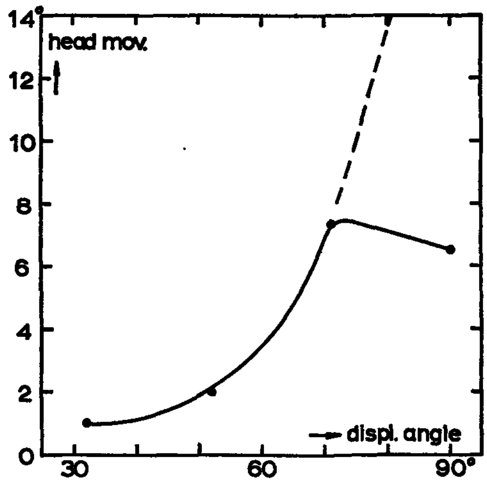


FIG. 30 - Head movements as a function of display angle in the memorizing task

DISCUSSION

The following points emerge from these results.

a. The error percentage increases as a function of display angle. This is only true if the selective mechanism is not overloaded. It is striking that the increase in errors rose sharply between 71° and 90° which is the area where the transition from eye- to headfield was found in previous experiments.

In terms of the theory, we can say that as long as the material can be sampled in one selective act, performance is reasonable while the intake of information becomes very deficient, under the present experimental conditions at least, when the material must be gathered in two selective acts.

It should be noticed that no drop in performance is found between 20° and 40° – i.e. the area where the transitions from the stationary field to the eye field was found in the original experiments. This may be due to the fact that nearly maximal performance was already possible in the eyefield, so that no differentiation between the two fields could appear. Another possibility is that the stationary field is absent in tasks where several signals are presented simultaneously. It is known that mutual inference occurs when viewing several signals with peripheral vision only. It is not unlikely therefore that the eyefield strategy is adopted, even at very small display angles. According to this reasoning, the stationary field may play a role only in tasks where a limited number of signals is present at a time.

b. The error percentage is independent of the display angle if the immediate memory is overloaded. This was the case when 8 randomly chosen signals were presented, the error percentage amounting to 35-40%, at all display angles. Presumably this percentage will be about the maximum that can be found in experiments like this. If a subject is purely guessing, he can obtain an average error percentage of 50% and during a presentation, he will transmit 1 or 2 signs at least – even under the worst conditions. Assuming a guess for the remaining signs, the error percentage will be no more than 40%.

The fact that this result is already obtained at a small display angle stresses that the immediate memory is overloaded indeed. The number of correct reproductions is less than when 6 signs are exposed, which result agrees with other experimental data (Fraisse and Battro 1960; Michon 1962).

After preparation of this manuscript, a study by Klemmer (1963) was received, that seems relevant for the present discussion. Linear dotpatterns were presented tachistoscopically by flashing randomly selected patterns on uniformly spaced lightbulbs. Twenty-one bulbs were used and the total visual angle was varied from 2.5° to 160°. Perception was determined by a poststimulus cue requiring only a 1-bit response. Under these conditions the percentage of errors proved independent of the display angle, but the error percentage was rather high all the time (between 30% and 40%).

In fact this agrees with our results: by overloading the perceptual system, performance becomes quite independent of visual angle. The fact that the errorpercentage remains below 50% reflects the idea just mentioned that some of the information comes through, enabling a somewhat better performance than would be predicted on the basis of guessing. At large display angles the subject is likely to select only that part of the light pattern that falls within the eyefield – and the data of Klemmer support this idea. Also in this case, therefore, overall performance will be better than chance.

In another condition the information load was lowered by restoring the light pattern after the poststimulus cue had appeared. In that case the errorpercentage decreased considerably for display angles smaller than 80° – which is very similar to the result of our immediate memory experiment. The findings can obviously serve as an extra support for our theory. Klemmer himself – although he noticed this peculiar effect of information load on performance – holds in his summary that "Average accuracy of report was surprisingly insensitive to visual angle." After the present discussion some of this surprise might be taken away.

c. The effect of redundancy on the recall of 6 and 8 signs. A striking finding is that the redundancy only exerts an effect if the immediate memory system is overloaded. No significant differences were present between the redundant and the random condition when 6 signs were presented, while a clear difference was found at 8 signs. Apparently the the recoding of the material in larger units takes place only when a more simple process lacks success.

If this is found to be more general, it is an important principle in perception. So far, we found one publication which arrived at the same conclusion i.c. that "perceptual organisation is a function of overloading and will not occur when the channel is operating below capacity" (Allan 1961). Allan presented the alphabet in a random order and instructed the subjects to memorize this sequence either by the "Whole" method or by the "Parts" method. It was found that the former instruction yielded much better results, suggesting that when the organism is overloaded recoding of material is more likely to take place.

d. The effect of redundancy is dependent on the display angle. Beyond 70°, the effect of redundancy has also disappeared at the 8 signs condition. Apparently the redundancy is not recognized, so that the recoding process cannot take place. This result is highly important since it completely confirms the prediction. Beyond the eyefield the material is split up in order to be processed in two selective arts. Furthermore, it is confirmed that under the latter condition, the parts are not easily integrated and recoded. If that was possible there is no reason why the effect of redundancy should be absent beyond the eyefield.

The latter conclusion is premature however, since we must consider the possibility that the second selective act has been impossible as a consequence of the short presentation time.

In that case it is quite natural of course that the redundancy was not recognized. The argument is even more likely in view of the results of fig. 30 where it was found that only a fraction of the expected head movements are made. So, at a longer presentation time, the redundancy may be noticed, so that the present data cannot be considered as conclusive.
In order to obtain more evidence about the effect of the redundancy when two selective acts are involved, we should know first at which presentation time the subject is capable of carrying out an inspection of the whole display. If a longer inspection time is allowed we expect the head movements to increase, according to the dotted line in fig. 30. This course is suggested from the earlier measurements in exp. 4 and 5. When the maximal value is reached, we can suppose that the second selective act has been possible.

EXPERIMENT 15a

METHOD AND PROCEDURE

The experimental set up was similar to that of experiment 15. Only the variables were changed. The random series of 8 signs were presented at a display angle of 90°. The presentation time was varied (1, 2, 3, 4 sec.). 12 new subjects were tested under all conditions in a counterbalanced order. At each presentation time two different series were given. Before the experiment started, the subjects received a few training series in order to be acquainted with the task. Head movements were measured during performance.

RESULTS

The mean data – degrees of head movements and error percentages – are presented in table 43 and fig. 31.

TABLE 43 - Mean error percentage and degree of head movements as a function of presentation time

presentation time	degree of head movements	error percentage
1 sec	5.2°	43.8
2 sec	15.6°	28.1
3 sec	17.6°	14.4
4 sec	17.8°	8.0

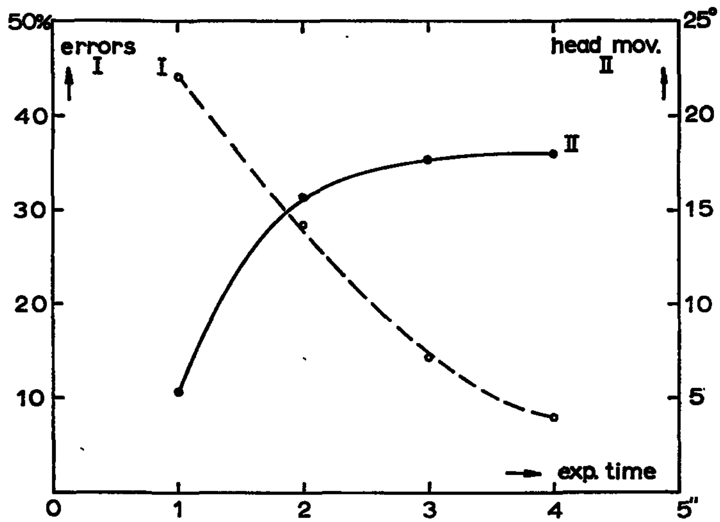


FIG. 31 - Errors and head movements as a function of presentation time
(8 signs; display angle 90°)

STATISTICAL ANALYSIS

An analysis of variance was carried out on the head movements data after a $\sqrt{x + 0.5}$ transformation.
A significant increase of head movements as a function of presentation time appeared ($F = 17.96$, $p < 0.001$). A similar analysis of the errors revealed a decrease of errors as a function of presentation time ($F = 12.90$, $p < 0.001$). The increase in head movements was mainly due to a substantial rise between 1 and 2 seconds. No significant difference was present between the degree of head movements between 2 and 4 seconds. Performance improved significantly up to a presentation time of 3 sec.

These results confirm the earlier expectation that head movements are inhibited at a presentation time of 1 sec. Allowing 2 seconds inspection of the signs, it appears that the head movements have reached their maximal value. The average error percentage at 2 seconds presentation shows that about 6 signals per series could be recalled correctly, which is in the order of the memory span. The further decrease at 3 and 4 seconds can be ascribed to rehearsal effects of the transmitted signs. This process is likely to support quick transition of material from *immediate memory to more lasting forms of memory* –even after a very short time of memorization (Sanders 1961).

Returning to the question of redundancy when two selective acts are involved, we can say that the second selective act will be possible anyhow at a presentation time of 2 seconds. If the redundancy is recognized, therefore, we should expect a better result when the signs are redundant than when they are not, at 2 seconds presentation.

EXPERIMENT 15b

METHOD AND PROCEDURE

12 new subjects recalled each 4 series of signs, both of the 8 signs-redundant and of the 8 signs-random type, under a display angle of 90° and with a presentation time of 2 seconds. The order of the conditions was counterbalanced. The results are shown in table 44.

TABLE 44 - Mean error percentage at the recall of 8 signs under a display angle of 90° and presented for 2 seconds, under redundant and random conditions

Condition	Mean error percentage
8 signs-redundant	22.3
8 signs-random	19.8

No significant evidence was found for a difference between the mean error percentages. Therefore the conclusion can be made that redundancy is not recognized under these conditions. In itself this is important since it connects this work with other experiments on selective perception (see chapter 1, p. 25). The most interesting feature with respect to our theory is still that recognition of the redundancy is possible until the display exceeds the eyefield, which offers a new argument for the idea that a fundamental change in selective strategy occurs at the transition from eye to headfield.

As to the structure of the selective process – it offers the suggestion that the succession of selective acts is accompanied by a series of rules. One seems to be that a common principle – redundancy – in two successive selective acts is not easily detected. Coding and recoding of perceptual material occurs per selective act. How far this is a general rule is open to further research. So it seems plausible that if the content of one selective act is "meaningful", the connection with subsequent acts will run more easily. This was suggested already in chapter 1 and needs further investigation.

A further extension of exp. 15 can be important to test another prediction. We may start from the finding that, when memorising 8 signs under a display angle of 90°, the degree of head movements depends on the presentation time. At the arrival of the signs, the first selective activity is to handle some signals that are within the eye field. Presumably the whole eye field will not be covered in the first selective act – on the basis of experiment 13 and 14 – but instead, the display field will be split in two – probably equal – parts. Further the activity in this first act is supposed to consist of two parts: First we have the period of "hypotheses formation" about the signs, which are covered but are not in the region of clear vision. Secondly, we expect some eye movements to check the hypotheses. Then the head is moved and the process is repeated in the same way.

EXPERIMENT 15c

METHOD AND PROCEDURE

Series of 8 signs of the random type were presented for 1 sec., under several display angles (32°, 52°, 72°, 90°). As in the main experiment 4 series were carried out per display angle. Every subject was exposed to all conditions in a counterbalanced order. Throughout the runs, the amplitude of both eye and head movements, carried out during viewing of the signs, was measured. Also the time between the onset of the stimulus and the start of the eye and head movements was recorded. 4 subjects took part.
The mean data are shown in table 45 and fig. 32.

TABLE 45 - Mean data on degree of eye- and headmovements and on the period between start and onset of movements as a function of display angle

Display angle	degree of eye-movements	degree of head-movements	period without movements
32°	13.7°	0°	48 sec
52°	21.0°	0°	48 sec
71°	25.2°	0°	41 sec
90°	33.5°	0°	30 sec

The results show that no head movements were made. The degree of eye movements increased linearly with the display angle but in no case was the angle covered completely.
The prediction that a period should be found without any movements is

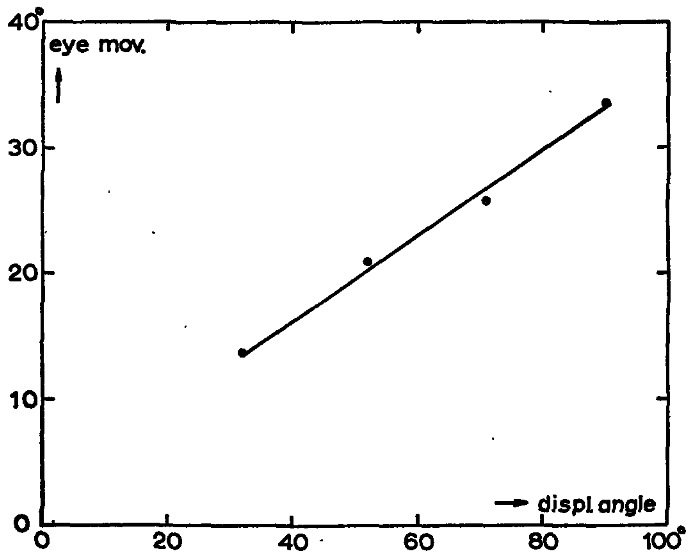


FIG. 32- Eye movements as a function of display angle in the memorizing task (8 signs; presentation: 1 sec.)

confirmed by the present data. The period appears to be relatively constant with a tendency to decrease at the largest display angle. This was found with all subjects, but it failed to reach statistical significance ($F = 2.44$ $p > 0.05$), owing to the small number of subjects.
Before commenting upon these results, we will proceed with a similar experiment, where the presentation time was varied.

EXPERIMENT 15d

METHOD AND PROCEDURE

Series of 8 signs, not redundant, were presented at a constant display angle (90°), while the viewing time was varied (1. 2. 3 sec.). 2 Trials were carried out per condition. 6 subjects were tested in a counterbalanced order. Measurements were obtained of the amplitude of eye and head movements, carried out during viewing. Also the times between the onset of the stimulus and the start of eye and head movements were recorded.
The mean data are shown in table 46 and fig. 33.

TABLE 46 - Mean data on eye and head movements as a function of viewing time in the memorising task

Viewing time	degrees of eye movem.	degrees of head movem.	peripheral viewing	period without headmov.	degrees of eye mov. before start of head mov.
1 sec	41.2°	2.0°	.40 sec	.86 sec	24.4°
2 sec	61.5°	8.2°	.43 sec	1.24 sec	35.2°
3 sec	71.6°	11.3°	.46 sec	1.44 sec	37.6°

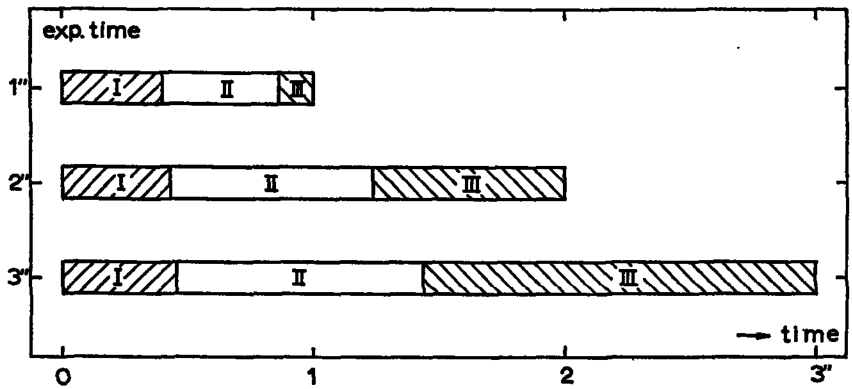


FIG. 33 - Analysis of movements of eye and head as a function of presentation time. (8 signs; display angle: 90°)
I: eye fixated (peripheral viewing); II: eye movements; III: head movements

STATISTICAL ANALYSIS

The following appeared from the analyses of variance:

a. The degree of eye and head movements increases as a function of presentation time (resp. $F = 15.2$ $p < 0.01$ and $F = 8.62$ $p < 0.05$). T-tests showed a lasting increase of eye amplitude between 2 sec. and 3 sec. but no significant increase of the head movements (see table 46).

b. There was no evidence for a significant difference of peripheral viewing period as a function of presentation time. The period without head activity increased clearly however ($F = 6.90$ $p < 0.05$) – especially between 1 and 2 sec. Correspondingly, the degree of eye activity, before the head movements started, increased ($F = 6.78$ $p < 0.05$).

The results of the experiments are in agreement with the theoretical sketch of the selective process: the first selective act starts, indeed, with a period without motor activity, followed by eye movements and, at a fairly late stage, the eye shifts are supplemented by head movements.

The period of peripheral viewing proved to be independent of the display angle, although it tends to decrease when the display angle exceeds the eye field. The latter trend is reasonable, since in the case of one selective act – as is supposed in the eyefield – hypotheses must be obtained about all items. When two selective acts are involved, only a limited number of items are covered during the first selective act, sothat less time should be needed to build up the hypotheses at that stage of the process.

At a display angle of 90°, the peripheral viewing period proved to be constant if the presentation time was varied (see fig. 33). Apparently, a standard time is needed for the first period, in which the hypotheses are build up. According to the theory, the first period of viewing is the basic process of the selective act. If this activity is carried out deficiently, the further "checking" period will also be defective. It is reasonable therefore that no restrictions can be imposed upon the peripheral viewing period, if the total presentation time is small.

There seems to be a relationship, however, between the length of presentation and the start of the head movements. At longer presentation times head movements are started at a later stage, than when this time is short. It may be said that, when time is lacking, the subject takes less time to check his hypotheses and turns more rapidly to the material that was neglected in the first selective act.

When the display angle is varied and the presentation time is one second (table 45), the eye movements tend to cover a constant portion of the display field – somewhat less than $\frac{1}{3}$. This seems natural, when we consider that at larger display angles the shifts from one sign to another increase in length. The finding that about 37° of the display-field is covered before head movements enter the picture (table 46) can also serve as an argument in favour of the theory. It shows that three or four signs are inspected before the head shifts. Moreover the 37° agree beautifully with the visual angle where the drop in reaction time occurred in exp. 13. It will be remembered that we suggested that about 35° would be covered during the first selective act in that experiment.

It may seem odd that at a 1 sec. presentation the eye movements also cover a restricted part of the display angle, if the latter is small (table 45). It agrees, however, with our suggestion that the 1 sec. period is too short to check all hypotheses. If the number of signs is small, however, we would expect a better result in this respect. We will even predict that in this case the two selective acts can be carried out, which implies that head movements will already reach the maximum value at a 1 sec. presentation time. From experiment 15 we can suggest that with 6 signs, this will still be impossible – in view of the error percentage when the subjects were tested under a display angle of 90°. It should be possible with 4 signs however: we will close with a test of this hypothesis.

EXPERIMENT 15e

METHOD AND PROCEDURE

At a constant presentation time of 1 sec., series of signs were presented, which contained either 4, 6 or 8 items. Before a series was presented the subject was informed about the number that would be given. 6 subjects performed all conditions in a counterbalanced order. The display angle was 90°.

EXPERIMENT 15f

METHOD AND PROCEDURE

A group of 6 subjects recalled 2 series of signs under three different display times (1 sec; 2 sec; 3 sec;). The series contained 4 items and the order of the conditions was counterbalanced. Another group of 6 subjects had the same procedure, with the difference that the series contained 6 items. Head movements were measured during performance.

RESULTS

The mean data are presented in table 47 and fig. 34.

STATISTICAL ANALYSIS

The following appeared from the statistical treatment, which consisted of three analyses of variance.

a. A significant difference in degree of head movements is present.

TABLE 47 - Head movements and errors as a function of presentation time and number of signs

Number of signs	head movements	errorpercentage	head movements per presentation time		
			1 sec	2 sec	3 sec
4	15.5°	0	19.3°	22.5°	22.0°
6	10.6°	32.3	12.0°	19.2°	19.4°
8	8.7°	33.5	5.2°	15.6°	17.6°

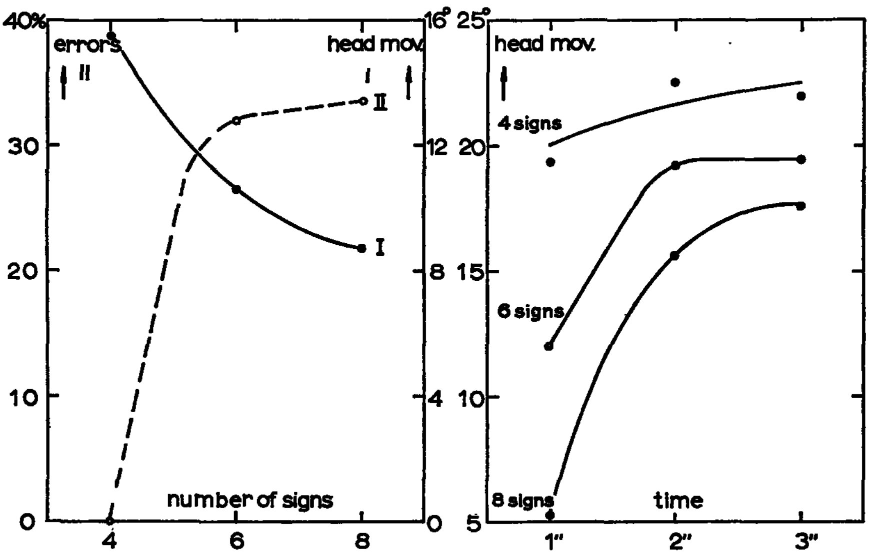


FIG. 34 - Errors and head movements as a function of number of signs and of presentation time. (display angle 90°)

When a smaller number of signs is presented, larger head movements appear ($F = 7.03$ $p < 0.05$).

b. The latter result applies only with a presentation time of 1 sec. At longer presentation times no significant differences in degree of head movements are found as a function of number of signs.

c. If 4 signs are presented, the degree of head movements does not change significantly if the presentation time increases ($F = 1.22$ $p > 0.1$). When 6 items are exposed the head activity increases as a function of presentation time ($F = 5.90$ $p < 0.05$).

The results confirm the prediction that more head activity occurs at 1 sec. presentation if less information is present in the display. If 4

signs are given, the maximum degree is already reached at 1 sec., which suggests that under these conditions the two selective acts can be carried out. When 6 signs are presented the head movements have not reached the maximum value – which corresponds with the finding that the error percentage is high.
As a general conclusion from exp. 15, we can say that the experimental results fit the theory about the selective process. The results can be readily explained by the hypothesis that, at a display angle which exceeds the eyefield, at least two selective acts become necessary to sample the information. The experiments have mainly described the intake during the first selective act. First there is a peripheral viewing period, then a period of eye activity, and only after considerable time has passed does the head becomes active. Whether the second selective act is carried out in the same way is less clear from the present discussion. Further research is needed on this point. It may be possible that during the verification of the hypothesis, obtained in the first selective act, new hypotheses are already formulated. In this way, the two selective acts may follow each other in a flexible way. A final remark may be devoted to the effect of transition from the stationary field to the eyefield. It has already been mentioned that no evidence for a rupture in performance is found in the area around 30° and it should be added that in experiment 13 also no clear effect of the stationary field could be found. In that experiment reaction time was only shorter if two successive signals were equal, while a shift from a signal to the nearest one immediately gave rise to a considerable increase in reaction time, although the visual angle that was to be bridged was only 10°-15° (see fig. 21 and 22).
The transition from the stationary field to the eyefield may have a limited functional importance therefore. Pure grouping, as a strategy, may only be used in situations where only a limited number of spatially separated signals are present – as was the case in chapters 2 and 3. Another restriction may be that the complex of signals does not contain more than a certain amount of information – for the mere reason that the channel capacity is limited. It is likely that if the pure grouping strategy fails, the "semigrouping process" sets in automatically.
It is recognized that these statements are unsatisfactory, especially in so far as no clear areas can be indicated as to where to expect an effect at the transition from stationary field to eyefield, and where not. For a better understanding of the selective process in the functional visual field, this question should be answered.

CHAPTER 5

THREE MINOR EXPERIMENTS ON VISUAL SELECTION

So far it has been shown that the predictions from our theory were confirmed in a number of reaction tasks and also in a memorizing experiment. Now we will turn to some tasks of a different nature i.c. some psychophysical situations. Experiment 16 deals with estimation of distance in the left-right dimension. Experiment 17 will deal with pointer adjustements. A final experiment is devoted to the effect of display angle on performance, in case the display has also an outspoken vertical element. The latter factor has been neglected so far, although it is likely to exert an effect.
The general hypothesis is equal for all three situations. If the display angle exceeds the eyefield, a drop in performance is expected. Whether a similar effect will occur at the transition from the stationary field to the eyefield has become doubtful, in view of the results of chapter 4.

1. Distance estimation as a function of display angle

EXPERIMENT 16

METHOD AND PROCEDURE

The subjects were seated on an adjustable chair at 60 cm distance from a horizontally mounted rail: on the rail, three lights were fixed; one was placed on the meridian at eyelevel (a). Another was found left from the subject (b); its actual position was varied during the experiment. The third light was placed to the right of the subject and closely to the meridian (c). An illustration of the set up is presented in fig. 35.

Light c could be moved along the rail by handling a chord that was fixed at the table, at which the subject was seated. The experimental task was to move light c to the right, until the mutual distances between the lights appeared equal. To exclude external cues the task was performed in the dark.
Forty subjects – air force ratings – took part in the experiment. They

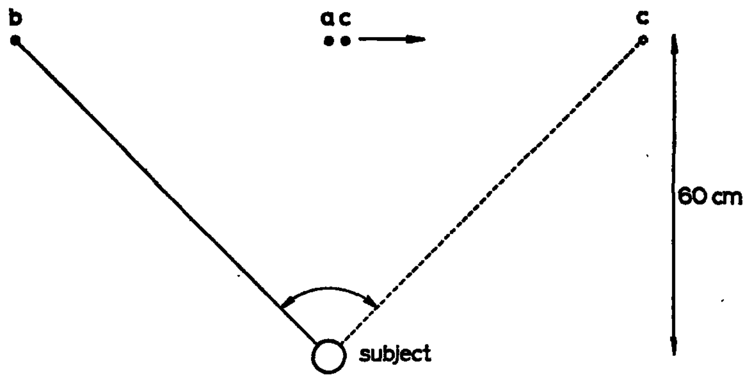


FIG. 35 - Schematic drawing of the distance estimation task

were randomly divided into four equal groups. Each group was tested at one condition only. As mentioned, the distance a-b was varied, amounting to 50, 70, 90, 110 cm. Consequently the task was performed under a display angle of 83°, 98° 112°, or 124°. Every subject made five adjustments in succession.

HYPOTHESIS

In terms of the theory, the subjects will receive a clear hypothesis about the positions of all lights – and consequently about their mutual distances – in one selective act, as long as the display angle does not exceed the eyefield. Thus the comparison between the standard distance and the adjusted distance is thought to be carried out at once. This will change in the headfield. Now two selective acts are required: one devoted to the standard and a second one to the adjusted distance. The greater complexity of the latter process is likely to affect the accuracy of performance and, therefore, the difference limen will be larger.

At the average-error method – which is used in this experiment – the difference limen is usually expressed in terms of dispersion of successive judgments. Guilford (1954) mentions the probable error, the standard deviation or the average deviation in this respect. There is no special reason to expect a clear change in the mean error of adjustment, since the presumed change in inspection strategy does not predict a systematic over or underestimation of the adjustments. In general the standard is likely to be constantly underestimated in the present situation, since the space error is not controlled.

The mean standard deviations and errors per group are presented in table 48 and fig. 36.

TABLE 48 - Mean standard deviation and mean error as a function of display angle

Display angle	Mean standard deviation	Mean error
83°	1.43	– 2.3 cm
98°	2.61	– 5.5 cm
112°	4.90	– 4.0 cm
124°	5.04	– 10.6 cm

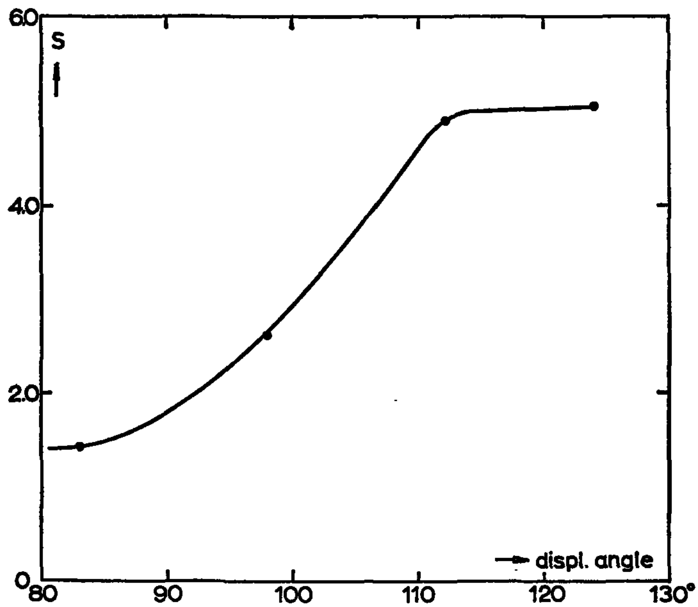


FIG. 36 - Standard deviation as a function of display angle in the distance estimation task

STATISTICAL ANALYSIS

a. standard deviations: an analysis of variance was carried out to determine the statistical significance between groups. A logarithmic transformation of the data was required, since means and variances tended to correlate. The difference in mean between display angles was highly significant ($F = 20.3$ $p < 0.001$). A t-test analysis showed that the major part of this variance was due to the increase between 98° and 112°.

b. Errors: application of a similar statistical procedure to the errors revealed that no evidence was present for a significant difference between groups ($F = 2.12$ $p > 0.05$).

DISCUSSION

As expected the results show quite an inconclusive picture as far as the mean error is concerned. Since errors are generally negative we can conclude that the standard was underestimated, but the display angle had no effect on the degree of errors. The standard deviations – reflecting the ability of the subject to reproduce his own adjustment – differed significantly however. It can be readily assumed that at display angles up to 83°, no striking change of standard deviation will occur. Between 83° and 112° a striking increase in difference limen shows up, – especially between 98° and 112° according to the statistical analysis – while beyond 112° a new function tends to arise. The discontinuity is clearly present.

This rather sudden increase confirms the hypothesis that a change occurs in the subject's strategy of comparing standard and variable. It can be noted that the rupture occurs at a larger display angle than was found in the previous experimental settings. This can be explained again in terms of task complexity. It can be assumed in fact that, perceptually, the present task belongs to the easiest that have been used.

Another feature of the present results concerns the fact that the increase in standard deviation tends to start before the transition from eye-to headfield takes place – i.c. between 83° and 98°. So the discontinuity seems more gradual than at the previous experimental tasks and we wonder why. The most plausible explanation – in terms of our theory at least – is that at the borderline of the eyefield the hypotheses have become so weak, that their effect decreases. But in that case it should be asked why the effect of the weaker hypotheses was absent in the previous experiments.

The solution of this problem may be given in terms of number of alternative signals. In the previous tasks each signal had only one degree of freedom, while there are numerous alternatives in the present experiment – when taking the adjusted distance as the "signal". Now it has been shown that the hypotheses about signals near the border of the eyefield are weak – witness the low confidence values in experiment 10. It is plausible however that in the case of one alternative, the hypothesis can always be formulated, since it is a question of "either – or". When there are more alternatives, the formulation will become increasingly difficult however.

In fact the gradual decrease of performance in the eyefield was also present in the memorizing task (experiment 15), although in that setting the signals had only one degree of freedom. Here, the condition that all signals had to be memorized in a short period may have decreased the effect of the hypotheses. It is clearly established, however, that beyond the eyefield the hypothesis formation does not exist any more. On this point both the data of exp. 15 and of the present experiment are equivocal.

As to the transition from the stationary field to the eyefield, it is noted that again no effect of this transition is found in performance. Although no measures are obtained in the stationary field, it is highly improbable that the standard deviation will still diminish at smaller display angles. In fact, this result is not surprising: Whether the signals are grouped in one selective act or "semi-grouped" will not differ in the present kind of situation. Possibly, however, the increasing trend of the standard deviation starts slowly after the transition to the eyefield. To check this suggestion, the range of measurement should be extended.

It is recognized that some interpretations of the results are unsatisfactory since no head movements have been measured. This was difficult to accomplish in view of the experimental design. We shall proceed therefore with the analysis of another psychophysical situation in which such will be done.

2. *Pointer adjustment as a function of display angle*

EXPERIMENT 17

METHOD AND PROCEDURE

Two circular discs (diameter 20 cm) were mounted on equal distances from the subjects meridian on eyelevel. On both discs a pointer was fixed with a length of 7.5 cm and a width of 1 cm. The pointer position of the left disc was constant throughout the experiment (120°) and the task consisted of adjusting the right pointer to the position of the left one.

Again the display angle was the experimental variable. One group of 6 subjects was tested under 66°, 78° and 96°; another group of 12 subjects under 66°, 96°, 106° and 110°. The order of the conditions was counterbalanced according to a Latin Square design. The subjects made 5 adjustments per condition. The task was carried out in a dark room and therefore the pointers were illuminated by means of fluorescent paint. During the task, the head movements of the subjects were measured. Data were obtained concerning (i) the standard deviation of the adjustments and (ii) the head movements.

HYPOTHESIS

Following the same reasoning as in exp. 16, we expect a rapid increase of the difference limen as the display angle under which the discs are viewed, approaches the headfield.

RESULTS

The mean data are presented in table 49 and fig. 37.

TABLE 49 - Standard deviation and head movements as a function of display angle in the pointer adjustment task

Display angle	Mean standard deviation		Degree of headmovements	
	Group I	Group II	Group I	Group II
66°	1.28	1.48	1.3°	1.6°
78°	1.80	–	3.3°	–
96°	2.26	2.02	11.9°	14.8°
106°	–	2.74		24.3°
116°	–	2.76		34.2°

STATISTICAL ANALYSIS

Group I: After a logarithmic transformation of the data – which treatment was needed in view of heterogenity of variance – an analysis of variance was carried out on the standard deviations and on the head movements. It was found that the difference between display angles was not significant ($F = 4.23$ $0.1 > p > 0.05$) as far as the mean standard deviation is concerned. The degree of head movements increased strongly as a function of display angle ($F = 38.3$ $p < 0.001$).
Group II: A similar analysis, as applied to group I, revealed a significant increase of mean standard deviations ($F = 5.01$ $p < 0.01$) and of

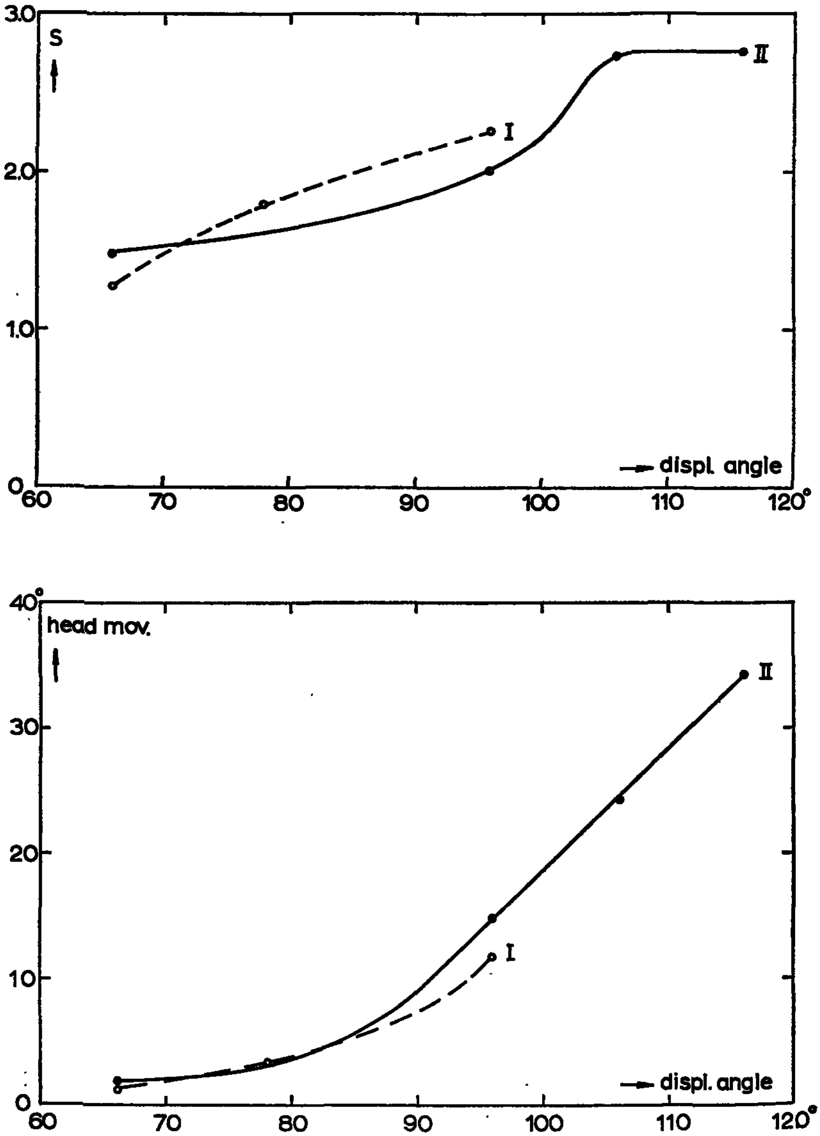


FIG. 37 - Standard deviation and head movements as a function of display angle in the pointer adjustment task. I: Group I; II: Group II

head movements ($F = 50.2$ $p < 0.001$). As to standard deviations, a difference of .70 between two means proved to be necessary to reach the 5% level of significance (t-test).

DISCUSSION

It appears from the head movements measurements that the transition from eye – to headfield probably takes place between 96° and 106°. Beyond this area an increase in display angle is entirely compensated by head movements. In this area, performance follows a similar course as in experiment 15 and 16: A relatively strong increase of dispersion between 96° and 106°, followed by a rather flat part between 106° and 116°, and preceded by a slight increasing tendency. It will be clear that the similarity in results of experiment 16 and the present one, permits a similar interpretation. Following the same reasoning as before (page 153) we can assume an exponential course of the curve between 0° and 96°. In the present experimental set up the number of degrees of freedom of the response is large again, so that the weakening of the obtained hypothesis towards the borders of the eyefield will affect the results. Therefore no sudden drop is found, but an exponential increase in the eyefield.
It will be noticed that the increase in standard deviation is less than in the distance estimation task. Apparently the number of discriminable categories is less in that setting. This is not altogether surprising, since a circular display is known to have a higher dimensionality than a horizontal one (Sleight 1948).

3. Digits comparison as a function of display angle

EXPERIMENT 18

METHOD AND PROCEDURE

Two hard board sheets (length 76 cm; width 17 cm) were mounted vertically on a black screen. Both sheets were covered with white flanel on which ten black cards (length 5.5 cm; width 3.5 cm) were fixed. On the cards white digits had been drawn, with a length of 4 cm. The distance between successive digits was also 4 cm. In general two corresponding digits were equal. Only in some instances a deviation was introduced. This is illustrated in fig. 38.

The hardboard sheets were thus placed on equal distances from the subjects meridian that the fifth horizontal pair was found at eyelevel. The subjects were instructed to read aloud all pairs of digits from top to bottom – five-five, seven-seven etc. – and to report afterwards the number of pairs in which the digits deviated from each other. They

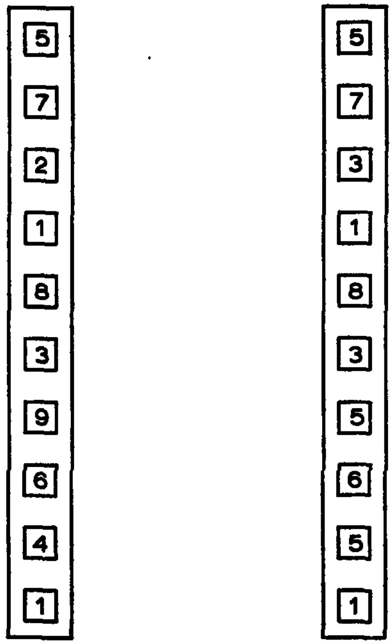


FIG. 38 - Schematic drawing of the digit comparison task

were asked to work as quickly and accurately as possible. The time, needed to read aloud was measured by means of a stopwatch in tenth of seconds.

All subjects performed the task seven times under various display angles and various digit-columns The order of testing was counterbalanced in a Greco-Latin square design. The following display angles were used: 16°, 32°, 50°, 66°, 82°, 94°, 104°. Accordingly seven sets of digit columns were constructed in which the number of unequal pairs was varied. 4, 3 or 2 unequal pairs were present in two sets each; in one set there was only one unequal pair. This variation was introduced to avoid rapid learning during the experimental session.

14 subjects – naval ratings – took part in the experiment. They were divided in two equal groups, so that two Greco-Latin squares could be composed. The second square was a replication of the first one. During performance head movements were measured. Since errors in the reports of the number of unequal pairs occurred rarely, they were neglected in the treatment of the data.

HYPOTHESIS

The general trend of the hypothesis is clear: the transition from eye- to headfield will exert an effect on performance.
In view of the discussion of experiment 16 and 17 however, we wonder which form this effect will take; either the drop-form, as found in, chapter 2 and 3, or the form of an exponential function in the eyefield – as was shown in the previous experiments On one hand, we can maintain that the latter will occur since the digits contain several degrees of freedom. On the other hand however, we can argue that the information is recoded to an equal-unequal dichotomy, in which case there remains only one degree of freedom. In other words, if a left digit is fixated, the obtained hypothesis about the right digit is expressed in terms of equal versus unequal. From this argument a drop-like course at the transition from eye to headfield seems the most adequate hypothesis.
What will happen at the stationary field-eyefield transition? So far, we can conclude that at least two conditions are essential in order to find a decline in performance. First, the number of signals should be limited – in the horizontal plane at least – and secondly, reaction time measurements should be obtained. Both conditions are fulfilled in the present setting so that we expect to find an effect.

RESULTS

The data are presented in table 50 and fig. 39.

TABLE 50 - Mean reaction time and degree of head movements as a function of display angle

Display angle	Mean reactiontime	Mean degree of headmovements
16°	7.25″	0°
32°	7.28″	0°
50°	8.06″	2.50°
66°	8.86″	7.40°
82°	9.50″	15.00°
94°	11.16″	29.00°
104°	11.53″	38.40°

STATISTICAL ANALYSIS

An analysis of variance on reaction times showed a significant difference between trials ($F = 7.46$ $p < 0.01$), between digit columns

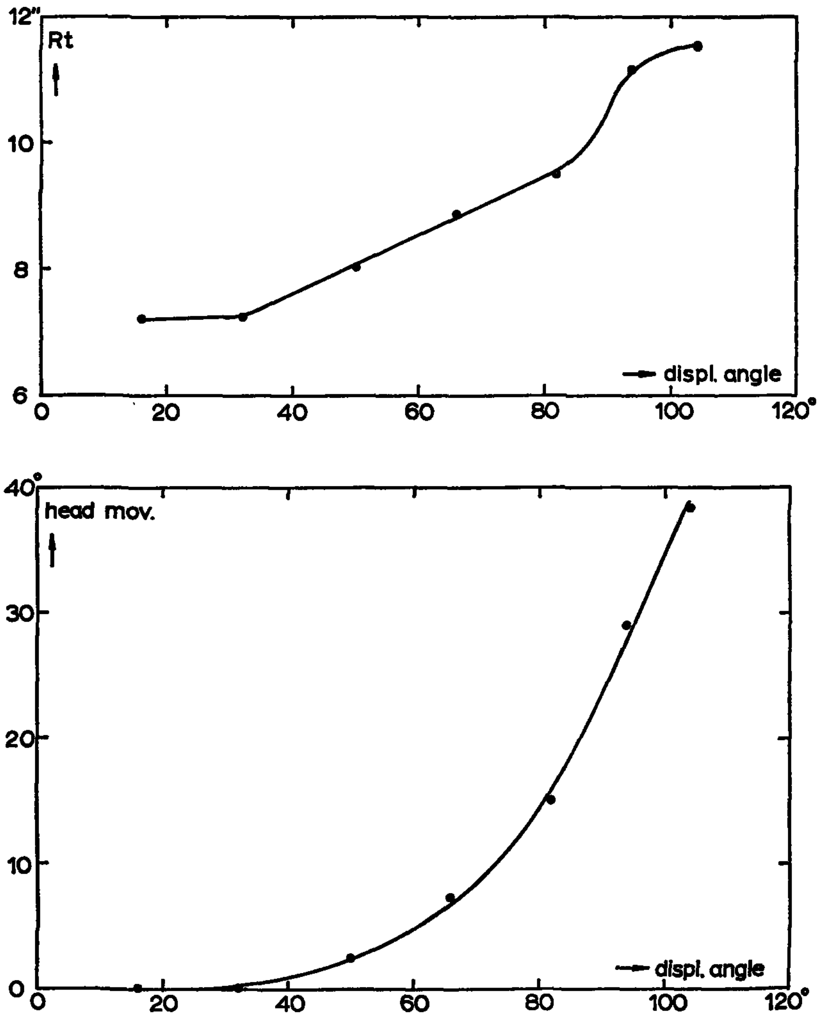


FIG. 39 - Reaction time and head movements as a function of display angle *in the digit comparison experiment*

($F = 3.93$ $p < 0.01$) and between display angles ($F = 44.38$ $p < 0.001$). Further the relationship between reaction time and display angle was tested for linearity. It appeared that the variance around regression proved to be significant ($F = 3.18$ $p < 0.05$), and with this confidence the relation cannot be represented by a straight line. T-tests showed that the mean increase between successive display angles was significant at the 5% level if a difference between two means was larger than 0.74 sec (1% level: Diff: 0.97 sec).

DISCUSSION

Inspection of table 50 and figure 39 shows that the decline of performance at the eyefield-headfield transition is indeed found. Again the drop occurs when head movements start to compensate the increase of display angle completely.

The linear increase of reaction time between 32° and 82°, and also between 94° and 104°, can be largely ascribed to an increase of movement time. Plotting the relation between movement time and display angle – see exp. 6 and 7 – in Fig. 39, we obtain a straight line, which runs parallel to the course between 32° and 82° and between 94° and 104°. This only holds if the movement time values are multiplied with a factor twenty, pointing to the idea that about twenty shifts from left to right – or from right to left – are carried out in one trial (see fig. 40a). The head movement-records support this idea; in all cases between 16 and 20 horizontal movements were recorded in one trial.

An alternative process could have been a regular sequence of horizontal and vertical shifts (see fig. 40b). In that case, only ten horizontal movements would be made, supplemented by nine vertical shifts. As to the length of the total track the latter process seems to be more efficient, but nevertheless the former process is followed in general. Presumably the organism prefers to have a left sided digit as a standard sothat he must return to left every time. This idea is in line with v. d. Meer's work on dynamic orientation (v. d. Meer 1958).

When the display angle becomes smaller than 32°, the movement time tends to become constant. Assuming that a horizontal saccadic eyemovement of 30° takes about 0.06 sec., this residual time amounts to about 1.20 sec. per trial. The curious phenomenon is that this time remains constant at smaller display angles which may be explained by a change in selective strategy. Instead of process A, subjects start to work according to process C (see fig 40). Then the movements of the eye are only vertical and therefore the timelength becomes independent of the display angle. This suggestion fits the theory that at small display angles a horizontal pair of digits can be transmitted completely in one selective act. In other words, at display angles smaller than 30° the angle is within the stationary field. This explanation remains

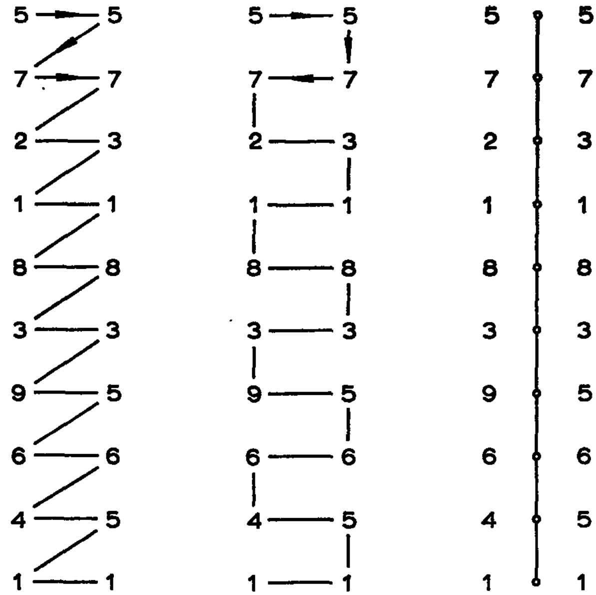


FIG. 40 - Selective strategies in the digit comparison experiment

tentative however, as long as it is not confirmed by the measurement of the actual patterns of the eye shifts.

In accepting this explanation we still have a great problem to solve. When we subtract the movement time from the reaction time, it appears that the discriminative processes in the stationary field and the eyefield take about the same time. There are no indications at all for a drop in performance at the transition from stationary field to eyefield. Thus, no time factor can be traced, which emphasises that Discr ($S_l + S_r$) – as supposed in the stationary field – is more efficient than Discr (S_l + hypothesis S_r) + check S_r – as is supposed in the eyefield.

It is not pretended that this problem can be solved on the basis of the present experimental material. We may suggest, however, that the strategies do not differentiate, due to the vertical composition of the display. It can be imagined that, during a selective act, several hypotheses are obtained in the eyefield. In fact, this was met already in previous experiments: in the search task as well as in the vigilance test and the memorizing task, the existence was assumed of several hypotheses at the same time (experiment 13-15). So, when the left digit of the upper row is fixated a hypothesis may arise about the right digit of the same row and also about both digits of the second row. During the check of the right digit of the first row, the other hypotheses may be confirmed at the same time, so that the discrimination time decreases enormously. This may be impossible in the stationary field, since the simultaneous intake of one horizontal pair of digits may largely fill up the capacity of the channel.

This interpretation is very speculative however, and much more research must be done to give it a firmer basis, but that is beyond the scope of this study. At this stage it can be concluded that the efficiency of performance is not exclusively determined by the structure of the selective acts (grouping – semi grouping – successive treatment). Within the limits of a particular display angle, the structure of the display also has an important effect.

CHAPTER 6

RETROSPECT AND PROSPECT

Having finished the discussion of the experiments we should like to devote a few pages to a summary of the main conclusions; to a reflection on the question howfar the results contribute to the knowledge of the selective process; and finally, to the outline of some problems for further research.

1. Summary of the conclusions

a. The relation between performance in a visual task and the display angle at which that task is carried out cannot usually be described by a linear function. The most striking divergence from linearity consists of a drop in performance at either one or two critical display angles.

b. The display angles, where the drops are found, coincide with 1. the marginal angle where the task can still be performed efficiently by the mere use of peripheral vision and 2. the marginal value where the task can still be performed by means of eye movements and peripheral viewing together.

c. Thus, on the basis of performance and of the mechanisms of visual orientation, three levels of the functional visual field can be discerned: *The stationary field,* where mere peripheral viewing already leads to efficient performance; *the eyefield,* where the supplementary use of eye movements is required; and *the headfield,* where head movements are also required.

d. The actual display angles where a transition from one level to another takes place, seems to be dependent on the complexity of the task. Factors such as discriminability of signal and number of signals to be inspected at once seem to affect the limits of a particular level.
   Generally, the first drop in performance is found between 20° and 35°, and the second one between 75° and 105° approximately.

e. The drops in performance cannot be attributed to a sudden increase of movement time at the transition from one level to another. They should rather be explained in terms of a change of selective strategy i.c. from a less to a more complicated perceptual process (chapter 2; 7, pag. 67).
f. Some evidence is gathered in favour of the theory that, when comparing the stationary field with the headfield, the selective process needs only one selective act in the former and at least two selective acts in the latter field, in order to handle the same amount of information – on the condition that this amount does not exceed the capacity of the transmission channel.
This theory is based upon two assumptions, i.c.
1. that human perception can be described in terms of a single channel communication system to some extent.
2. that the intake of information occurs discontinuously in separated perceptual samples, information "chunks" or selective acts (Chapter 3).
g. In the eyefield, the selective process is thought to be intermediate between that of the stationary field and the headfield. Not all information can be collected in one selective act, although valid hypotheses about the signals are obtained. Nevertheless, the hypotheses have to be checked in further selective acts. These acts can be carried out much more efficiently, however, than when no hypotheses are available – as in the headfield.
h. The grouping strategy is the most natural way of behaviour in the stationary field and the eye field, in the sense that they lead to the most efficient performance. They are not altogether compelling however, since successive handling of signals can occur if the subject is instructed to do so or perhaps if motivation is lacking.
i. The confidence value of the hypotheses, obtained in the eyefield, declines as the display angle draws near the border of the headfield. This does not exert an important effect on performance if the signals possess only one degree of freedom.
Performance is affected, however, if more alternative signals are present. In that case no sudden drop is found at the eye field – head field transition, but a gradual decline appears already in the eyefield (chapter 5). This is illustrated in fig. 41.
j. Presumably, the eyefield-headfield transition has a more general functional significance than the transition from the stationary field to the eyefield. Particulary if the task is not of the reactiontime

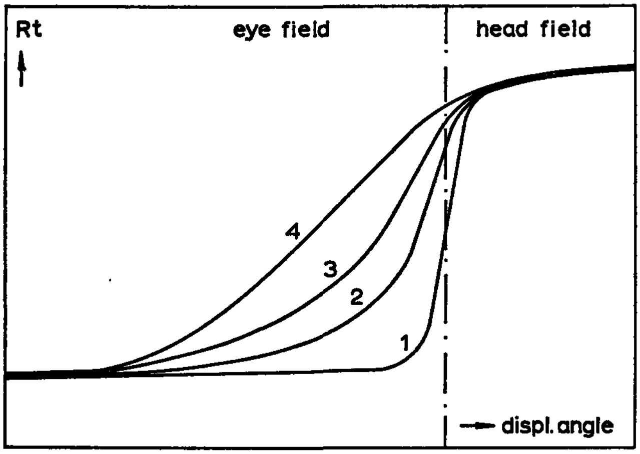


FIG. 41 - The hypothetical effect of information-per-signal on the relation between reaction time and display angle. The numbers (1, 2, 3, 4) refer to an increasing amount of information per signal

type, the latter transition seems to have no effect on performance. If reactiontimes are asked, the stationary field is largely absent if the task has a complex character. The effect of going from the eyefield to the headfield was present in all experiments.

k. The specific way, in which the eyefield-headfield transition affects performance, does not necessarily take the form of conclusion b. or i. It also varies with the specific structure of the task (chapter 4; 1,2).

l. In search tasks with a larger number of signal sources, it appears that the two selective acts – which are required in the headfield – cover each about half of the display field. Thus, not all signals that are within the eyefield are selected in the first act (chapter 4; 1, 3).

m. It appears that under certain conditions a common principle in a series of simultaneously presented signals is not recognized if the material has to be split up and is transmitted in two successive acts. This occurs especially if the common principle consists of sequential redundancy (chapter 4; 3).

These are the main conclusions that can be drawn from the experiments. It will be clear that conclusion A up to and including H are general statements while the remaining theses try to relate the general findings with particular characteristics of experimental situations. Only those that appear established in a more than tentative way have been listed. Moreover only those conclusions have been mentioned that are directly related to the main argument of this study.

A major point that has been vaguely mentioned in this list concerns the effects of motivation on the selective process. This was done in view of the fact that we have only dealt with motivation on a few occasions; e.g. in the vigilance experiment (chapter 4; 2). In that case an effect was found in the form of a general slowing down of the selective process. If this is found to be more general we may suggest that motivational variables will have a great effect on the selective strategy – also in short lasting tasks. For instance, a badly motivated subject may fail to obtain hypotheses about signals in the eyefield and then the shape of the relationship between performance and display angle is likely to change considerably.

We may also comment upon conclusion J and K: These are mainly derived from the results of chapter 4 and 5 and they stress that interaction between the selective strategy and the structure of the functional space is an essential determinant of performance. It is clear that in the present study only a few factors could be traced in more than a vague way. Some other factors – e.g. the effect of the vertical dimension (experiment 18) – could be mentioned without it being possible to integrate them in our theory. The investigation of such factors is one of the main experimental prospects.

As to the theory, which has been developed to integrate the findings, we want to stress its preliminary character. It has had the advantage however of stimulating a number of experiments and of providing a theoretical framework to a number of phenomena – as on the funnelling of attention, on noise and multisource displays etc.

2. *Major implications of the conclusions*

a. The structure of selective process. The intention of this study was to investigate if we could get hold on the course of the selective process in the functional visual field (chapter 1, 7). Has this trial been successful? In a way it has, witness the theory about the selective process that has been developed; but on the other hand a series of main questions has remained unanswered. It is still impossible to measure the selective acts directly. The time limits of a selective act are still largely unknown. Something has been gained concerning the contents of a selective act, although they were not measured directly but had to be judged by comparing the relative efficiency of grouping and successive handling

(chapter 3). In general: the selective act has remained a theoretical inference rather than a measurable fact. The concept ought to have more operational anchors before a more differentiated theory about set, attention and the like can be developed from the behavioral side.
In spite of the fact that we have not yet arrived at measuring techniques, we wish to maintain that progress can be expected from the analysis of the functional visual field. The present experimental work should be considered as no more than a first start. In our opinion the experimental possibilities are very numerous indeed. The problem of overloading and its effect on grouping, for instance, may provide important new data about the course of the selective process. In fact this point has been raised in the experiments of Conrad (1951, 1954, 1955) and of Mackworth and Mackworth (1959) but their treatment of the experimental data does not allow an analysis in terms of grouping or successive handling of signals. The measurement of eye movements already proved indispensable in reaching a more differentiated analysis of the data in our study, and simultaneous recording of performance and eye movements will be one of the best methods for analysing the course of the selective process.
A further problem, worth mentioning concerns the elaboration of conclusion M, which may provide a criterion to what has been transmitted in one selective act and what in the next one – for certain situations at least. In our experiment on refractoriness (chapter 3), it was shown that grouping of signals was preferred up to an interval of .2 sec. between S_1 and S_2. This offers some idea of the maximal time limits of the selective act – for these stimuli at least.
In this way, more suggestions for experiments might be enumerated. Detailed suggestions have been given already at the discussions of the experiments however.

b. The problem of perceptual load

Strongly related with progress of knowledge on the selective process is the practical problem of the measurement of perceptual load. The latter term is used here in the broad sense of "the difficulty of a largely mental task". Since Woodrow's early trial to measure difficulty (Woodrow 1936), an increasing interest in this topic has come into existence. As one of the main experimental entrances investigators have considered the determination of the socalled "Spare mental capacity" by means of an additional task next to the main task (see chapter 1,

p. 24). Sometimes this has taken the form of increasing the information-to-be transmitted until a maximum was reached, while in other studies subjects were instructed to generate information during the performance of the main task (Baddeley 1962, Michon 1963).
The latter method has the obvious advantage that it can be used in combination with a larger variety of experimental tasks. Both methods have the obvious disadvantage that the main task may be either neglected in favour of the additional task, or that the additional task may even stimulate performance in the main task – especially in vigilance situations, where the organism is continuously underloaded. A curious phenomenon in this respect has been reported by Brown (1963) who found the "spare capacity" of drivers to be greater towards the end of an 8 hour workspell than at the beginning. So, the effect of fatigue was inverse to what might be expected. It may be supposed however that feelings of boredom towards the main task caused an extra motivation towards the additonal work.
Next to the principle of the additional task, we might consider wether our experiments can deliver some indications to the measurement of perceptual load. This idea arises from conclusion D, dealing with the relationship between the levels of the functional visual field and the complexity of the task. To consider this possibility, we will list below the various tasks that were involved in our research in combination with the transition areas from one level to another.

	Transition points	
	1	2
Circumscription of the task	Stationary field eyefield	Eyefield headfield
1. Continuous reaction task. Discrimination between 4 dots and 5 dots. One reaction to two simultaneously presented signals (experiment 1 and 2).	19°-34°	73°-86° 81°-94°
2. Idem, but discrimination between 2 dots and 3 dots	31°-49° 34°-52°	73°-86° 81°-94°
3. Continuous reaction task. Discrimination between 4 and 5 dots. Every reaction is a choice of one signal out of	—	68°-81°

six that are presented simultaneously (experiment 13)		
4. Vigilance task. Detection of strong decrease of brightness at 16 possible positions. (experiment 14)	—	94°-104°
5. Memorizing task. (memorizing of 6 or 8 plus and minus signs) (experiment 15)	—	71°-90°
6. Distance comparison in the horizontal plane (exp. 16)	—	98°-112°
7. Pointer adjustment in the horizontal plane (exp. 17)	—	96°-106°
8. Digit comparison on equality in the horizontal plane (experiment 18)	32°-50°	82°-94°

Consideration of this list shows that the data can only give a rough estimate. In most cases the areas are too big, due to a lack of measurements in the experiments. If necessary, further experimentation can be devoted to obtain more precision.

Now, if any, the eyefield-headfield transition will be a criterion for perceptual load, since only in three cases the stationary field-eyefield transition appeared in performance. Now, indeed, there are considerable differences between the tasks as to the eye field-headfield transition area.

Assuming that this area correlates with the degree of perceptual load, task 3 would be the most difficult one, while task 4, 6 and 7 would belong to the easiest of the series.

One of the ways to investigate whether this is true or not could be by means of judgments of subjects who know all the tasks thoroughly. Within the present framework such an undertaking is hard to realize and therefore one might suggest trying it out on a number of industrial tasks. An impression of the eyefield-headfield transition point may be obtained without measurement of the actual performance of the tasks. Just measurement of head movements as a function of display angle may be sufficient.

As to the present series of tasks, it can be mentioned, that rankorder judgments of 4 subjects were obtained, who were in some way acquainted with the tasks.

A general Spearman Rankorder correlation of $+ .67$ ($p. < 0.02$) was obtained between judgments and transition points, which emphasises that subjective judgment of difficulty can probably be related to the eyefield-headfield transition.

The main divergence between the rankorder and the transition points proved to exist at the vigilance task. This test was considered to be more difficult that appeared from the transition point.

Probably "perceptual load" and difficulty are not correlated one to one. It would be better to assume a kind of u-shaped relation – so that with strong underloading of the organism, the difficulty of a task increases again.

The disadvantage of this method of measuring perceptual load seems to be that it is only applicable to a limited number of tasks – i.c. those where several information sources are to be handled at the same time. On this point it is clear that the method of the additional task is much better.

c. The relation between selection and cognition

The results have again emphasised the intrinsic bond between selection and cognitive behaviour. As pointed out in chapter 1, the relation between these concepts has always been a problem in the history of experimental psychology and the ideas have varied from strict separation to complete confounding of selection and cognition. Both extremes have been rejected at that stage. The discussion in chapter 1 and the subsequent experiments have shown that selection is an essential condition in arriving at cognition. In spite of this close connection however, the concepts should be distinghuished. A related problem is whether selectivity should be ultimately defined in terms of the material with which the organism is dealing. When we speak about selective perception and learning etc., it is implied that we assume essentially different mechanisms to be involved under conditions of perception and learning.

On the other hand we may suppose that the organism disposes of one selective mechanism, having some general characteristics.

This question was briefly touched at the discussion on Gibson's list of names for selectivity (see page 3). After the argument of this study we would rather defend the latter viewpoint without losing sight of the fact that the actual selective strategy will be based on the material that is going to be transmitted. But modifications of selective strategy do

not alter the fact that more general laws of selectivity may exist. For instance, the eyefield-headfield transition exerted an effect on performance in all tasks used in this study, even though the actual mode of appearance depended on the structure of the task.
Now, it is admitted that the experimental tasks all belonged to a rather restricted behavioural area. All the time visual perception was investigated. But, especially as far as the sequence of the selective acts is concerned, the results correspond with the selective phenomena in the auditory field, and further, with rehearsal in learning situations.
Thus, although the time is not ripe to be conclusive, the present results point rather in the direction of a general selective mechanism, with direct connections to memory, motivation and external stimulations, in order to be informed which strategy is most efficient.

SUMMARY

In this thesis some problems on the selective process at the perception and assimilation of information are under discussion. The study consists of 6 chapters: The first one is of historical and theoretical character and is followed by 4, mainly experimental chapters. Finally, the main conclusions are summarized and some implications of the results are discussed (Chapter 6).

In general, the existence of a selective principle in behaviour has been recognized, although it has been scarcely incorporated in most theoretical formulations. In fact, there is no theory about the selective process and the research was mostly of incidental and unsystematic character. Only in the last decennium has this changed.
The concepts of "attention" and "set" are frequently used to indicate the selective principle. "Set" refers mainly to the determining backgrounds of selection, like habits, perceptual schemata, attitudes and also certain kinds of instruction. The attention concept has an intensity aspect next to a selection element. In a short historical summary, the main – mostly classical – theories of attention are analysed and this analysis shows that generally only one of the fore mentioned aspects is included in the definitions. Sometimes, attention is identified with set, thus losing its specific meaning. In many cases attention is taken exclusively in the sense of intensity. It is pointed out that in that case no adequate methods of measurement can be developed – not by behavioural means at least – since the attention factor becomes confounded with the specific perceptual properties of the situation.
It is stated that the attention concept looses its meaning in all one-sided definitions. An operational approach towards attention can be reached only by a consequent integration of selection and intensity. This is illustrated by the "blocking phenomenon" in continuous work, where it appears that intensity is measurable by the course of the selective process.

A promising approach to the phenomena of set and attention is only possible if a more detailed knowledge has been obtained about the selective process. For, in this way it would be possible to measure every instant which is selected, and also those that are not. The filter theory of Broadbent is principally engaged with this problem and therefore it is discussed at some length. Two notions in relation to the selective process are emphasised. First, the idea of the "single channel" transmission of information and the limited capacity of the channel. Secondly, the idea that the course of the selective process is essentially discontinuous and consists of a sequence of perceptual samples or selective acts. The analysis of the selective process can be carried out in this way by consideration of the selective act. Questions about the time-limits, the intake capacity and the mutual relationship of the selective acts seem especially important. Now, the literature shows that there are a large number of indications, pointing towards the mentioned postulates, but also that the properties of the selective act are difficult to estimate.

Then, it is proposed to investigate in how far possibilities are present in an analysis of the selective process in the functional visual field. The advantage of measurements of eye movements in this field is especially mentioned. A type of experiment might be carried out in which two signals are presented simultaneously at a variable display angle. If this angle is small, both signals may be taken in one selective act (grouping). At large display angles this would not be possible, and two selective acts are likely to be required in order to transmit the signals.

In this way the theoretical analysis ends in an experimental program where performance is measured as a function of display angle.

In *Chapter 2* some experiments of the forementioned type are carried out. It appears that the relation between performance and display angle is linear within certain limits, but this trend is interrupted twice by a rather abrupt drop in performance. It is shown experimentally that eye- and headmovements respectively become necessary in order to reach optimal performance at those display angles where the drops were found to occur. The "movement" hypothesis – which assumes that the drops are due to a sudden increase in movement time of eye or head – is rejected, since movement time appears to be related lineary with display angle.

Meanwhile, three levels can be discerned in the functional visual field i.c. (i) *the stationary field* – characterized by the fact that performance is optimal by the mere use of peripheral vision, (ii) *the eyefield* – where eye movements are needed to complement peripheral vision, and (iii) *the headfield* – where head movements are also required. It is suggested that a specific selective strategy dominates each functional level, which is likely to shift from grouping in the stationary field towards successive treatment of signals in the headfield. The idea is treated in some detail in *Chapter 3*. It is found in several experiments that, at simultaneous presentation of two signals, the reactiontime to S_2 is considerably shorter than that to S_1 – and is also shorter than normal – under the condition that the signals are given within the limits of the stationary field or the eyefield. In the headfield Rt_1 equals Rt_2. The drops in performance can be ascribed to this decrease of Rt_2. This decrease is independent of training in the stationary field, but not in the eyefield. Moreover the effect is more outstanding in the stationary field. Both in the stationary field and the eyefield reaction times are considerably longer, when subjects are instructed to handle the signals in succession – compared with the reaction times on the instruction to group the signals. Apparently, the subjects use an inefficient selective strategy in the former case.

Three hypothetical selective strategies are described on the basis of the experimental results – one for each level of the functional visual field:

Stationary field: Here, a pure grouping process is assumed. In formula: Discrimination ($S_1 + S_2$) → Reaction S_1 → Reaction S_2.

Headfield: Here it is likely that the selective acts are transmitted in successive selective acts: Discrimination S_1 → Reaction S_1 → Discrimination S_2 → Reaction S_2; or: Discrimination S_1 → Discrimination S_2 → Reaction S_1 → Reaction S_2.

Eyefield: Presumably the process takes an intermediate form between grouping and successive handling. S_1 is assimilated in one selective act and at the same time subjects can obtain a hypothesis about S_2. In a so-called check-act this hypothesis must still be verified. However, the speed in which a check-act can be carried out is probably much higher than the speed of a "new" selective act, as in the headfield. So: Discrimination (S_1 + hypothesis S_2) → check S_2 → Reaction S_1 → Reaction S_2. In further experiments, the "hypothesis S_2"-theory is tested in a direct way. It appears that subjects can give a correct judgment about S_2, while they fixate S_1, if the display angle does not exceed the eyefield. In the headfield the judgment about S_2 is founded on guessing. Confidence in the judgments is small however in the eyefield and this fits the idea that only a "hypothesis" is obtained.

Within the stationary field confidence is great, which fits the idea that the signals are processed in one selective act.
The chapter ends with a discussion on grouping vs. successive handling of signals that are presented successively with a short time interval. In the literature on this point – i.c. the "psychological refractory period" – both assimilation-mechanism are mentioned, although grouping is not accepted generally. Two experiments are carried out to shed light on this point. It appears that grouping and successive handling can be equally efficient under certain conditions, sothat small differences in the experimental settings – e.g. instructions – may favour the occurrence of any strategy.
The theory about the selective process – as developed in chapter 3 – is based upon the analysis of only one very simple experimental task. It is the aim of *Chapter 4 and 5* to investigate in how far the theory is confirmed in more complex tasks. This is done successively in a visual search task, a vigilance task, a memorizing task, two psychophysical settings and a digit-control task. Performance is measured as a function of display angle in all cases. Beside some conclusions with specific meaning for one kind of experimental task, some suggestions of a more general character arise: 1. in general the results fit the theory. This holds especially for the eyefield-headfield transition. There is evidence however that the stationary field-eyefield transition has only a restricted significance. It is suggested that especially at complex tasks the stationary field does not play a role in performance.
2. The actual eyefield-headfield transition point tends to correlate with the difficulty of the task.
3. The typical drop in performance at the eyefield-headfield transition is affected by the numbers of degrees of freedom of the signals. The more degrees of freedom, the more the drop gets a more gradual character, and moreover it tends to start already in the eyefield itself.

Chapter 6 contains an enumeration of the main conclusions and a short discussion on the implications of the experiments to the measurement of the selective process. In that context the practical problem of the measurement of perceptual load is also touched upon.

SAMENVATTING

In dit proefschrift komen een aantal problemen aan de orde omtrent het selectief proces bij het waarnemen en verwerken van informatie. De studie bevat 6 hoofdstukken, waarvan het eerste historisch theoretisch van opzet is; het wordt gevolgd door 4 overwegend experimentele hoofdstukken. Tenslotte worden de voornaamste conclusies samengevat en enige implicaties van het werk besproken (hoofdstuk 6).

In het algemeen is het bestaan van het selectief beginsel in het gedrag wel erkend, maar in de meeste theoretische formuleringen over het gedrag is het nauwelijks geïncorporeerd. Van een theorie over het selectief principe kan niet worden gesproken en de research heeft meestal een incidenteel en onsystematisch karakter gehad. Pas in het laatste decennium is hierin enige verandering gekomen.
De begrippen "aandacht" en "instelling" zijn veelvuldig gebruikt om het selectief principe aan te duiden. Het laatstgenoemde begrip wijst daarbij voornamelijk naar de aansprakelijke achtergronden voor de selectie, zoals gewoonten, perceptieve schemata, instellingen en ook bepaalde instructies.
Het aandachtsbegrip bevat behalve een selectief element ook een intensiteitsaspect. In een korte historische samenvatting worden de voornaamste – meestal klassieke – aandachtstheorieën geanalyseerd, waarbij naar voren komt, dat meestal slechts één van de genoemde aspecten in de definities is opgenomen. Zo wordt in sommige gevallen aandacht met "set" geïdentificeerd, waarna het begrip zijn specifieke betekenis verliest. Vaak heeft men ook onder aandacht uitsluitend de intensiteit van de gerichtheid willen verstaan. Er wordt aangetoond dat in het laatste geval, via gedragsexperimenten althans, geen adequate meetmethodiek voor de intensiteit kan worden gevonden, omdat het "aandachtsaspect" niet van de specifieke perceptie te onderscheiden valt.
Er wordt gesteld dat het aandachtsconcept bij elke eenzijdige definitie zijn zin verliest. Een operationele benadering van de aandacht is

slechts te bereiken door een consequent volgehouden integratie van selectie en intensiteit in de definitie. Dit wordt geïllustreerd met het "blokkeringsverschijnsel" bij continue arbeid, waar blijkt dat de intensiteit van de aandacht in principe meetbaar is door een analyse van het verloop van het selectieve proces.
Een doeltreffende benadering van set- en aandachtsverschijnselen is slechts mogelijk indien een meer gedifferentieerde kennis over het selectief proces aanwezig is. Via deze weg zou men nl. van moment tot moment kunnen meten wat wel of wat niet geselecteerd wordt. Er is een recente theorie – nl. de filtertheorie van Broadbent – die zich voornamelijk met deze problematiek bezighoudt en deze wordt in extenso besproken. O.a. worden twee postulaten t.a.v. het selectief proces benadrukt. Ten eerste het idee van de "single channel" verwerking van informatie, waarbij aansluit dat dit kanaal een beperkte capaciteit bezit. Ten tweede, de opvatting dat het verloop van het selectief proces essentieel diskontinu is en bestaat uit een opeenvolging van "perceptual samples" of selectieve akten. De analyse van het selectief proces kan nu worden verricht door de beschouwing van de selectieve akt. Met name, vragen over de tijdslimieten, de opnamecapaciteit en de onderlinge verhouding van selectieve akten lijken essentieel.
De literatuur wijst nu uit dat er wel een groot aantal aanwijzingen zijn, die voor de genoemde postulaten pleiten, maar dat de eigenschappen van de selectieve akt niet gemakkelijk te benaderen zijn.
Er wordt dan voorgesteld om na te gaan in hoeverre een analyse van het selectief proces in het z.g. "functionele gezichtsveld" mogelijkheden biedt. Met name wordt gedacht aan de voordelen die oogbewegingsmetingen in dit gebied geven.
Er wordt gedacht aan een type experiment, waarin twee signalen simultaan worden aangeboden onder variable gezichtshoek. Als de gezichtshoek klein is kan worden verwacht dat beide signalen in één selectieve akt worden opgenomen (groeperen). Bij grotere gezichtshoeken zou dit niet meer mogelijk zijn en tenminste twee selektieve akten worden dan noodzakelijk geacht om de signalen op te nemen (successieve behandeling).
Op deze wijze loopt de theoretische analyse uit op een experimenteel programma waarbij prestatie als functie van de aanbiedingshoek wordt gemeten.

In Hoofdstuk 2 worden enige experimenten verricht van het zojuist beschreven type. Het blijkt dat de relatie tussen prestatie en gezichts-

hoek bij de gebruikte taak binnen bepaalde grenzen lineair is, doch bij twee critieke gezichtshoeken – 20° – 40° en 80° – 90° – wordt het lineaire verband door een betrekkelijk abrupt prestatieverval doorbroken. In volgende experimenten wordt aangetoond dat bij de critische gezichtshoeken respectievelijk oog- en hoofdbewegingen noodzakelijk worden om een maximale prestatie te bereiken.
De hypothese dat het verval in prestatie aan een sterke stijging van bewegingstijd van oog of hoofd te wijten zou zijn, wordt op grond van experimenten verworpen. Intussen kunnen dus binnen het functionele gezichtsveld drie niveaux onderscheiden worden, nl. *het stationaire veld* – waarbinnen de taak met behulp van peripheer zien bevredigend kan worden verricht – *het oogveld* – waarbinnen het juist genoemde waarnemingsmechanisme de aanvulling van oogbewegingen behoeft – en tenslotte *het hoofdveld*, waar ook nog hoofdbewegingen noodzakelijk zijn. Er wordt gesuggereerd, dat binnen elk van deze niveaux een specifieke selectieve strategie dominant is, die zou verschuiven van groeperen in het stationaire veld naar een successieve opname van signalen in het hoofdveld.
Deze laatste gedachte wordt nader uitgewerkt in *Hoofdstuk 3*. In verschillende experimenten wordt gevonden dat bij simultane aanbieding van twee signalen de reactietijd voor S_2 aanzienlijk korter is dan die voor S_1 – en ook korter is dan normaal – indien de signalen zich binnen het stationaire veld bevinden. Eveneens is er sprake van een verkorting van Rt_2 als de signalen binnen het oogveld liggen, terwijl in het hoofdveld Rt_1 en Rt_2 niet meer verschillen.
De gevonden vervallen in prestatie kunnen uit de verkortingen van de tweede reactietijd worden verklaard. De verkorting van Rt_2 binnen het stationaire veld blijkt onafhankelijk van oefening, terwijl binnen het oogveld enige oefening vereist is om de verkorting te vinden. Bij een instructie om de signalen strikt onafhankelijk te behandelen is de reactietijd langer dan bij een instructie om de signalen te groeperen – binnen het stationair veld en het oogveld althans. Kennelijk dwingt men de proefpersonen in het eerste geval tot een inefficiente strategie.
Op grond van de experimentele resultaten wordt voor elk van de niveaux van het functioneel gezichtsveld de optimale selectieve strategie hypotethisch beschreven.

Stationair veld: Hier is een zuiver groeperingsproces van signalen aannemelijk: Discriminatie ($S_1 + S_2$) — Reactie S_1 — Reactie S_2.

Hoofdveld: Hier worden de signalen waarschijnlijk in opeenvolgende selectieve akten opgenomen: Discriminatie S_1 — Reactie S_1 — Discriminatie S_2 — Reactie S_2 of: Discriminatie S_1 — Discriminatie S_2 — Reactie S_1 — Reactie S_2.

Oogveld: Hier lijkt een tussenvorm tussen groeperen en successieve opname de meest aangewezen veronderstelling. In één selectieve akt kan S_1 worden opgenomen en kan de p.p. zich tevens een hypothese vormen over S_2. In een z.g. "check-act" wordt deze hypothese nog geverifieerd. Een "check-act" kan echter sneller worden uitgevoerd dan een geheel nieuwe discriminatieve akt. Dus: Discriminatie (S_1 + hypothese S_2) — check S_2 — Reactie S_1 — Reactie S_2.

In een volgend experiment wordt deze theorie op directe wijze getoetst. Het blijkt dat p.p.n. een juist oordeel over S_2 kunnen geven, terwijl S_1 wordt gefixeerd, zolang de gezichtshoek binnen het oogveld ligt. In het hoofdveld blijkt het oordeel over S_2 op gissen te berusten.
Het vertrouwen in het oordeel over S_2 is zeer laag in het oogveld, hetgeen pleit voor de opvatting dat slechts een "hypothese" verkregen wordt. Binnen het stationaire veld blijkt de confidentie groot te zijn, hetgeen past in de opvatting dat beide signalen in één akt kunnen worden opgenomen.
Het hoofdstuk wordt besloten met een bespreking van het "groeperen" versus "successief opnemen" van signalen, die niet simultaan maar met een kort tijdsinterval worden aangeboden. In de literatuur op dit punt – i.c. de "psychological refractory period" – worden beide verwerkingsmechanismen genoemd, hoewel vooral het groeperen weinig algemeen aanvaard is. Een tweetal experimenten worden uitgevoerd met het doel enig licht op dit punt te werpen. Het blijkt dat "groeperen" en "successief opnemen" onder zekere voorwaarden even doeltreffend kunnen zijn, zodat kleine nuances in de experimentele situatie – zoals instructie b.v. – hun optreden kunnen beïnvloeden.

De theorie over het selectieve proces, zoals in Hoofdstuk 3 ontwikkeld is gebaseerd op de analyse van slechts één zeer simpele experimentele taak. In de *Hoofdstukken 4 en 5* wordt nu nagegaan in hoeverre de theorie bevestigd wordt bij een aantal meer complexe taken.
Achtereenvolgens komen aan de orde een "visual search" taak, een

vigilantie taak, een inprentingstaak, een tweetal psychophysische taken en een cijfer-inspectie taak. In alle gevallen wordt de presentatie als functie van de gezichtshoek gemeten. Naast een aantal conclusies met specifieke betekenis voor de betreffende taak rijzen enige algemene suggesties nl.:

1. In het algemeen passen de resultaten in het raam van de theorie. Dit geldt vooral voor de oogveld – hoofdveld overgang. De stationair veld-oogveld overgang blijkt niet algemeen te worden teruggevonden. De suggestie wordt geopperd dat bij zeer complexe situaties het stationair veld geen rol meer speelt in de prestatie.
2. De plaats van de oogveld-hoofdveld overgang correleert enigszins met de moeilijkheid van de taak.
3. Het typische verval bij de oogveld-hoofdveld overgang kan worden beïnvloed door het aantal vrijheidsgraden van de aanwezige signalen. Des te meer vrijheidsgraden, des te meer het verval een meer geleidelijk karakter krijgt en bovendien meer binnen het oogveld komt te liggen.

Hoofdstuk 6 bevat naast een opsomming van de belangrijkste conclusies een korte beschouwing over de implicaties van de experimenten t.a.v. de meetbaarheid van het selectief proces. Ook het practische probleem van de meetbaarheid van perceptieve last komt nog ter sprake.

REFERENCES

ALLAN, M. D. (1961): Memorizing, recoding and perceptual organisation. Br. J. psych. 52, 25-30.

ALLPORT, F. H. (1955): Theories of perception and the concept of structure. N.Y. Wiley.

ALLPORT, G. W. (1937): Personality: a psychological interpretation. Constable and Co. Ltd.

ATTNEAVE, F. (1961): In defense of homunculi. In: Sensory communication. W. Rosenblitt Ed. N.Y. Wiley 777-781.

BADDELLEY, A. D. (1962): Some factors influencing the generation of random letter sequences. Exp. Psychol. Society. Paper to London meeting; Jan. 1962.

BAKER, C. H. (1958): Attention to visual displays during a vigilance task. I. Biasing attention. Br. J. psychol. 49; 279-288.

BARTLETT, F. C. (1953): Psychological criteria of fatigue. In: FLOYD, W. F. *and* WELFORD A. T.: Symposion on fatigue. H. Klewis & Co., London.

BARTLEY, S. H. *and* CHUTE, E. (1947): Fatigue and impairment in man. Mc. Graw-Hill N.Y.

BERLYNE, D. E. (1951): Attention, perception and behaviour theory. Psychol. Rev. 58; 137-146.

BERLYNE, D. E. (1951): Attention to change. Br. J. psychol. 42; 269-278.

BERTELSON, P. (1961): Sequential redundancy and speed in a serial two choice responding task. Quart. J. exp. psychol. 13, 90-102.

BERTELSON, P. (1963): S-R relationships and reaction times to new versus repeated signals in a serial task. J. exp. psychol. 65; 478-484.

BEXTON, W. H., HERON W. *and* SCOTT T. H. (1954): Effects of decreased variation in the sensory environment. Canad. J. psychol. 8; 70-76.

BIEL, W. C. *and* WARRICK, M. J. (1949): Studies in perception of timedelay. Amer. Psychologist 4; 303.

BILLS, A. G. (1931): Blocking: a new principle in mental fatigue Amer. J. psychol. 43: 230-245.

BINET, A. (1890): La concurrence des états psychologiques. Rev. Philos 29; 138-155.

BORGER, R. (1963): The refractory period and serial choice reactions. Quart. J. exp. psychol. 15, 1-12.

BORING, E. G. (1950): A history of experimental psycholgy. 2nd edition N.Y. Appleton Century Crofts.

BORNEMANN, E. (1942): Untersuchungen über der Grad der geistigen Beanspruchung. Arbeitsphysiologie 12; 142-172, 173-191.

BROADBENT, D. E. (1950): The twenty dials test under quiet conditions. Medical Research Council, Appl. Psychol. Research Unit.

BROADBENT, D. E. (1953): Noise, paced performance and vigilance tasks. Br. J. psychol. 44; 295-303.

BROADBENT, D. E. (1954): The role of the auditory localisation in attention and memory span. J. exp. psychol. 47; 191-196.

BROADBENT, D. E. (1957): Immediate memory and simultaneous stimuli. Quart. J. exp. psychol. 9; 1-11.

BROADBENT, D. E. (1957): A mechanical model for human attention and immediate memory. Psychol. Rev. 64; 205-215.

BROADBENT, D. E. (1958): Perception and communication. London, Pergamon.

BROADBENT, D, E. *and* GREGORY, M. (1961): On the recall of stimuli presented alternately to two sense organs. Quart J. exp. psychol. 13; 103-110.

BROADBENT, D. E. *and* GREGORY, M. (1963): Division of attention and the decision theory of signal detection (abstract in: Human performance Reports list no. 8. A.P.R.U. Cambridge (U.K.)

BOURNE, L. E. (1953): An evaluation of the effect of induced tension on performance. J. exp. psychol. 49; 418-422.

BROWN, I. D. (1962): Measuring the spare mental capacity of car drivers by a subsidiary auditory task. Ergonomics 5; 247-250.

BROWN, I. D. (1963): Measuring fatigue in car drivers by a subsidiary task. Abstract in: Human performance Reports list no. 8. A.P.R.U. – Cambridge (U.K.).

BROWN I. D. *and* POULTON E. C. (1961): Measuring the spare mental capacity of car drivers by a subsidiary task. Ergonomics 4; 35-41.

BROWN, J. (1954): The nature of set-to-learn and of intra material interference in immediate memory. Quart. J. exp. psychol. 6; 141-148.

BROWN, J. (1958): Some tests of decay theory of immediate memory. Quart. J. exp. psychol. 10; 12-31.

BROWN, N. (1960): Attention: a theoretical note. J. gen. psychol. 62; 103-113.

BRUNER, J. S. (1951): Personality dynamics and the process of perceiving. In: Blake R. B. and Ramsey G. V.: Perception an approach to personality. N.Y. Ronald. 121-147.

BRUNER, J. S. (1957): On perceptual readiness. Psychol. Rev. 64; 123-152.

BRUNER, J. S. *and* GOODMAN C. C. (1947): Value and need as organizing factors in perception. J. Abnorm. soc. psychol. 42; 33-44.

BUSWELL G. T. (1922): Fundamental reading habits: a study of their development. Educ. Monograph Suppl. 21.

BURSILL, A. E. (1958): The restriction of peripheral vision during exposure to hot and humid conditions. Quart J. exp. psychol. 10; 113-130.

CARMICHAEL, L. *and* DEARBORN W. F. (1948): Reading and visual fatigue. Harrap & Co. Boston.

CHAPANIS, A. (1949): How we see: a summary of basic principles. Human factors in undersea warfare 3-60. Washington. Nat. Research Council.

CHERRY, E. C. *and* TAYLOR, W. K. (1954): Some further experiments upon the recognition of speech with one and with two ears. J. Acoust. Soc. Amer. 26; 554-559.

CONRAD, R. (1951): Speed and load stress in a sensori-motor skill. Brit. J. industr. Med. 8; 1-7.

CONRAD, R. (1954): Missed signals in a sensori-motor skill. J. exp. psychol. 48; 1-9.

CONRAD, R. (1955): Adaption to time in a sensori-motor skill. J. exp. psychol. 49; 115-121.

CORBIN, H., CARTER, J., REESE, E. P. *and* VOLKMANN, J. (1958): Experiments on visual search 1956-1957: Psychological Research Unit. Mount Holyoke.

COURTS, F, A, (1942): Relations between muscular tension and performance. Psychol. Bull. 39; 347-367.

CROSSMAN, E. R. F. W. (1955): The measurement of discriminability. Quart, J. exp. psychol. 176-195.

DALLENBACH, K. M. (1920): Attributive and cognitive clearness. J. exp. psychol. 3; 183-230.

DAVIS, R. (1956): The limits of the "psychological refractory period". Quart. J. exp. psychol. 8; 24-38.

DAVIS, R. (1957): The human operator as a single-channel information system. Quart. J. exp. psychol. 9; 119-129.

DAVIS, R. (1959): The role of "attention" in the psychological refractory period. Quart. J. exp. psych. 11; 211-220.

DAVIS, R. (1962): Choice reaction times and the theory of intermittency in human performance. Quart. J. exp. psychol. 14; 157-167.

DAVIS, R., MORAY, N. *and* TREISMAN, A. (1961): Initiative responses and the rate of gain of information Quart. J. exp. psychol. 13; 78-90.

DEININGER, R. L. *and* FITTS, P. M. (1955): Stimulus response compatibility, information theory and perceptual-motor performance. In: H. Quastler (Ed). Information theory in psychology. Glencoe: Free Press.; 316-341.

DODGE, R. (1905): The illusion of clear vision during eye movements. Psychol Bull. 2; 193-199.

DODGE, R. *and* CLINE, T. S. (1901): The angle velocity of eye movements. Psychol. Rev. 8; 145-157.

DREVER, J. (1958): Personal communication.

DREW, G. C. (1940): Mental fatigue: Flying personnel research committee report no. 227.

DUBOIS-POULSEN, N. (1952): Le champ visuel. Masson Paris.

DUFFY, E. (1951): The concept of energy mobilization. Psychol. Rev. 58; 30-40.

DUFFY, E. (1957): The psychological significance of the concept of "arousal" or "activation". Psychol. Rev. 64; 265-275.

ELIASBERG, W. (1930): Ueber Schwierigkeit und Ausslieszlichkeit im Seelischen: Die Enge des Bewusztseins in qualitativer Hinsicht. Arch. f. die Ges. Psychol. 74; 173-200.

ELITHORN, A. *and* LAWRENCE, C. (1956): Central inhibition: some refractory observations. Quart. J. exp. psychol. 7; 116-127.

FEILGENHAUSER, R. (1917): Untersuchungen über die Geschwindigkeit der Aufmerksamkeitswanderung. Arch. f. die Ges. Psychol. 25; 350-416.

FITTS, P. M. *and* SEEGER, C. M. (1953): S.-R. Compatibility: spatial caracteristics of stimulus and response codes. J. exp. psychol. 46; 199-210.

FITTS, P. M. *and* SIMON, C.W. (1949): Effect of horizontal vs. vertical stimulus separation on performance in a dual pursuit task. Amer. psychologist 4; 304-305.

FORD, A., WHITE, C. T. *and* LICHTENSTEIN, M. (1959): Analysis of eye movements during free search. J. Opt. Soc. Amer. 49; 287-292.

FRAISSE, P. (1957): La période réfractaire psychologique. L'Année psychol. 1957 (2); 315-329.

FRAISSE, P. *and* BATTRO, A. M. (1960): L'évolution de la capacité d'apprehension en fonction du temps d'exposition, L'Année psychol. 60; 295-307.

FRASER, D. C. (1953): The relation of an environmental variable to performance in a prolonged visual task. Quart. J. exp. psychol. 5; 31-32.

FREEMAN, G. L. (1948): The energetics of human behavior. Ithaca. N.Y. Cornell University Press.

FRENKEL BRUNSWIK, E. (1949): Intolerance of ambiguity as an emotional and perceptual personality variable. J. pers. 18; 108-143.

V. D. GEER, J. P. *and* MORAAL, J. (1962): Peripheral pattern identification (an experiment on dynamic vision). I.Z.F.-report 1962 – 18.

V. D. GEER, J. P. *and* LEVELT, W. J. M. (1963): Detection of visual patterns disturbed by noise. An exploratory study. Quart. J. exp. psychol. 15, 192-204.

GIBSON, J. J. (1941): A critical review of the concept of set in contemporary experimental psychology. Psychol. Bull. 38; 781-817.

GIBSON, J. J. (1959): Perception as a function of stimulation. In Psychology: A study of a science. S. Koch Ed. Vol. 1; 456-502. Mc Graw-Hill.

GLANVILLE A. D. *and* DALLENBACH K. M. (1929): The range of attention. Amer. J. psychol. 41; 207-236.

GOLDSTEIN, K. (1938): The organism. Am Book Co.

GRAHAM, C. H. *and* MARGARIA, R. (1935): Area and the intensity relation in the peripheral retina. Am. J. physiol. 113; 299-305.

GRAY, J. A. *and* WEDDENBURN, A. A. I. (1960): Grouping strategies with simultaneous stimuli. Quart. J. exp. psychol. 12; 180-185.

GRINDLEY, G. C. *and* ELWELL, J. L. (1939): The effect of knowledge of results on learning and performance. Br. J. psych. 29. 39-51.

GUILFORD, J. P. (1936): Varieties and levels of clearness correlated with eye-movements. Amer. J. psychol. 48; 371-388.

GUILFORD, J. P. (1946): General psychology. New York. Nostrand Co.

GUILFORD, J. P. (1954): Psychometric methods. New York. Mc Graw Hill.

HAKE, H. W. *and* GARNER, W. R. (1951): The effect of presenting various numbers of discrete steps on scale reading accuracy. J. exp. psychol. 42; 358-366.

HALLIDAY, A. M., KERR, M. *and* ELITHORN, A. (1960): Grouping of stimuli and apparent exceptions to the psychological refractory period. Quart. J. exp. psychol. 12; 72-89.

HEBB, D. O. (1949): The organisation of behavior. N.Y. Wiley.

HEBB, D. O. (1955): Drives and the C.N.S. (Conceptual Nervous System). Psychol. Rev. 62; 243-254.

HELSON, H. (1958): Adapation level as a basis for a quantitative theory of frames of reference. Psychol. Rev. 55; 297-313.

HICK, W. E. (1948): Discontinuous functioning of the human operator in pursuit tasks. Quart. J. exp. psychol. 1; 36-51.

HICK, W. E. (1952): On the rate of gain of information. Quart. J. exp. psychol. 4; 11-26.

HOLT, E. B. (1903): Eye movement and central anaesthesia. I. The problem of anaesthesia during eye movements. Psychol. Monogr. 17.

HYMAN, R. (1953): Stimulus information as a determinant of reaction time. J. exp. psychol. 45; 188-196.

JAMES, W. (1890): Principles of psychology. London 1890.

JERISON, H. J. (1957): Performance on a simple vigilance task in noise and quiet. J. acoust. Soc. Amer. 29; 1163-1165.

JERISON, H. J. *and* WING, S. (1957): Effects of noise and fatigue on a complex vigilance task. W.A.D.C. techn. rep. 57-14.

JOHANNSON, G. *and* BACKLUND, F. (1960): A versatile eye-movement recorder. Scand. J. psychol. Vol. 1; 181-186.

JOHANNSON, G. *and* BACKLUND, F. (1960): An eye movement recorder. University of Uppsala. Sweden. Report 8.

KARSLAKE, J. S. (1940): The Purdue eye-camera: a practical apparatus for studying the attention value of advertisements. J. appl. psychol. 24; 417-440.

KÄSTNER, A. *and* WIRTH, W. (1907): Die Bestimmung der Aufmerksamkeitsverteilung innerhalb des Sehfeldes mit Hilfe von Reaktionsversuchen. Psych. Stud. 3; 361-393.

KAUFMAN, E. L., LORD, M. W., REESE, T. W. *and* VOLKMANN, J. (1949): The discrimination of visual number. Amer. J. psychol. 62; 498-525.

KLEMMER, E. T. (1963): Perception of linear dot patterns. J. exp. psychol. 65; 468-474.

KÖHLER, W. (1925): Gestalttheorie und Komplextheorie. Psychol. Forschung 6; 358-416.

KÖHLER, W. *and* ADAMS., P. A. (1958): Perception and attention. Amer. J. psychol. 71; 489-504.

KORTE, W. (1923): Ueber die Gestaltauffassung im indirekten Sehen. Zeitsch. f. Psychol. 93; 17-82.

KOSTER, W. G. (1962): A new criterion in lighting studies. I.Z.F. report. 1962-2.

KREEZER, G. L., HIEL, J. H., MANNING, W. (1956): Attention: A bibliography and classification of the literature. W.A.D.C. technical report.

VON KRIES, J. (1913): Ueber die Bedeutung des Aufmerksamkeitssprunges für den Zeitsinn. Deutsche Zeitschr. f. Nervenheilkunde 47, 48; 352-393.

KÜLPE, O. (1904): Versuche über Abstraktion. Ber. über den Ie Kongresz für exp. Psychol. Berlin; 56-58.

LATOUR, P. L. (1962): Visual thresholds during eyemovements. Vision Research. Vol. 2. 261-262.

LEMMON, V. W. (1927): The relation of reaction time to measures of intelligence, memory and learning. Arch. psychol. N.Y. 94.

LEONARD, A. (1959): Tactual choice reactions. Part. I. Quart. J. exp. psychol. 11; 76-83.

LINCOLN, R. S. *and* AVERBACH, E. (1956): Spatial factors in check reading of dial groups. J. appl. psychol. 40; 105-108.

LUCHINS, A.S. *and* LUCHINS, E. H. (1950): New experimental attempts at preventing mechanisation in problem solving. J. gen. psychol. 42; 279-297.

MC. COMAS, J. C. (1922): A measure of attention. J. exp. psychol. 5; 1-18.

MACMILLAN, J. W. (1941): Eye movements and attention. Amer. J. psychol. 54; 374-384.

MACKWORTH, J. F. *and* MACKWORTH, N. H. (1958): Eye fixations recorded on changing visual scenes by the Television eyemarker. A.P.R.U. report 320-58. Cambridge U.K.

MACKWORTH, N. H. (1950): Researches on the measurement of human performance. M.R.C. spec. rep. series no 268. H.M. stationary office.

MACKWORTH, N. H. *and* MACKWORTH, J. F. (1959): Remembering advance cues during searching. Brit. J. psychol. 50; 207-222.

MARILL, T. (1957): The psychological refractory phase. Br. J. psychol; 48; 93-97.

MAGER, A. (1925): Neue Versuche zur Messung der Geschwindigkeit der Aufmerksamkeitswanderung. Arch. f. die Ges. Psychol. 53; 391-432.

MALMO, R. B. (1958): Measurement of drive: an unsolved problem in psychology. In M. R. Jones (Ed) Nebraska Symposium on motivation. Lincoln: Un. of Nebraska Press 1958; 229-265.

MALMO, R. B. (1959): Activation: A neuropsychological dimension. Psychol. Rev. 66; 367-386.

V. D. MEER, H. C. (1958): Die Links-Rechts-Polarisation des phaenomenalen Raumes. Wolters, Groningen.

METZGER, W. (1954): Psychologie; Darmstadt.

MICHON, J. A. (1962): Temporal structure of lettergroups and span of perception. I.Z.F. report 1962-12.

MICHON, J. A. (1963) Timing: a yardstick of perceptual burden. Paper to the Neth. Ergonomics Society, Leiden Meeting. June 1963.

MICHON, J. A. *and* KIRK, N. S. (1962): Eye movements in radar watchkeeping I.Z.F. report 1962-17.

MILLER, G. A. (1956): The magical number seven plus or minus two. Psychol. Rev. 63; 81-97.

MILLER, G. A. *and* SELFRIDGE, J. A. (1950): Verbal context and the recall of meaningful material. Amer. J. psychol. 63; 176-185.

MILLER, J. L., MC INTOSH, B. B. *and* COLE, E. L. (1954): Eye fixations of aircraft pilots. W.A.D.C. Techn. report no 53-220.

MORAY, N. (1959): Attention in dichotic listening: affective cues and the influence of instructions. Quart. J. exp. psychol. 11; 56-60.

MORAY, N. (1960): Broadbents filter theory: Postulate H and the problem of switching time. Quart. J. exp. psychol. 12; 214-221.

MOWBRAY, G. H. (1952): Simultaneous vision and audition: the detection of elements missing from overlearned sequences. J. exp. psych. 44; 292-300.

MOWBRAY, G. H. (1953): Simultaneous vision and audition: the comprehension of prose passages with varying levels of difficulty. J. exp. psychol. 46; 365-372.

MOWBRAY, G. H. (1954): The perception of short phrases presented simultaneously for visual and auditory reception. Quart. J. exp. psychol. 6; 86-92.

MOWBRAY, G. H. *and* RHOADES, M. V. (1959): On the reduction of choice reaction-times with practice. Quart. J. exp. psychol. 11; 16-23.

MOWRER, O. H. (1940): Preparatory set – some methods of measurement. Psychol. Monogr. No. 52.

MÜLLER, G. E. (1923): Komplextheorie und Gestalttheorie: Eine Beitrag zur Wahrnemungspsychologie. Göttingen 1923.

MUSICO, B. (1921): Is a fatigue test possible? Br. J. psychol. 12; 31-46.
NEILL MC. QUEEN, E. (1917): The distribution of attention. Br. J. psychol. Mon. Suppl. V.
PAULI, R. (1930): Die Enge des Bewusztseins und ihre experimentelle Untersuchung. Arch. f. die Ges. Psych. 74; 201-257.
PAULI, R. (1937): Mehrfacharbeit und Enge des Bewusztseins. Arch. f die Ges. Psychol. 98; 217-233.
POLLACK, I. (1952): The information of elementary auditory displays. J. acoust. Soc. Amer. 24; 745-749.
POLLACK, I. (1953): The information of elementary auditory displays. II. J. Acoust. Soc. Amer. 25; 765-769.
POULTON, E. C. (1950): Perceptual anticipation and reaction time. Quart. J. exp. psychol. 2; 99-112.
POULTON, E. C. (1956): Listening to overlapping calls. J. exp. psych. 52; 334-339.
POULTON, E. C. (1963): Peripheral vision, refractoriness and eye-movements in fast oral reading. Br. J. psychol. in press.
ROKEACH, M. (1951): Narrowmindedness and personality. J. Pers. 20; 234-251.
LE ROY BILLINGS, M. (1914): The duration of attention. Psychol. Rev. 21; 121-135.
RUBIN, E. (1921): Die Nicht-existenz der Aufmerksamkeit. Ber. über IX Kongress f. exp. Psychologie (Jena). 211-212.
RUEDIGER, W. C. (1907): The field of distinct vision. Arch. Psychol. N.Y. 5.
SANDERS, A. F. (1956): Tolerantie v.s. intolerantie voor ambiguiteit onderzocht bij de reactie op het autokinetisch effect en de stroboscopische beweging. Rapport W.W. 1956-8.
SANDERS, A. F. (1957): Over optisch seinen: Een analyse van de fouten gemaakt bij het ontvangen van morsetekens. Report W.W. 1957-12.
SANDERS, A. F. (1961): Rehearsal and recall in immediate memory. Ergonomics 4; 29-35.
SANDERS, A. F. (1961): The influence of noise on two discrimination tasks. Ergonomics 4; 253-259.
SANDERS, A. F. (1961): Aandachtsverschuiving en lawaaihinder. Ned .T. voor psychologie. XVI; 460-475.
SCHACKEL, B. (1958): A rubber section cup surface electrode with high electrical stability. J. Appl. physiol. 13; 153-158.
SCHOUTEN, J. F., KALSBEEK, J. W. H. *and* LEOPOLD, F. F. (1962): On the evaluation of perceptual and mental load. Ergonomics 5; 251-261.
SCHUBERT, E. D. *and* PARKER, C. D. (1955): Addition to Cherry's findings on switching speech between the two ears. J. acoust. Soc. Amer. 27; 792-794.
SENDERS, J. W., WEBB, J. B. *and* BAKER, C. A. (1955): The peripheral viewing of dials, J. appl. psychol. 433-436.
SENDERS, V. L. (1954): The effect of absolute and conditional probabilities distributions of instrument settings on scale reading. I. Repeated exposure to the same setting. W.A.D.C.. Techn. Rep. No. 54-253.
SLEIGHT, R. B. (1948); The effect of instrument dial shape on legibility. J. appl. psychol. 32; 170-188.
SMITH, S. L. *and* MILLER, G. A. (1952): The effects of coding procedures on learning and memory. Quart. progress report of Research Laboratory of

Electronics. M.I.T., to Air Force Human resources Research Laboratories. Dec. 1952, 7-10.

SOLOMON, R. L. *and* HOWES, D. H. (1951): Word frequency, personal values and visual duration thresholds. Psychol. Rev. 58; 256-270.

SUMBY, W. H. *and* POLLACK, I. (1954): Short time processing of information. H.F.O.R.L. report T.R.-54-6.

TELFORD, C. N. (1931): Refractory phase of voluntary and associative responses. J. exp. psychol. 14; 1-35.

THORNDIKE, E. L. (1914): Educational Psychology. Vol. III 1-142. New York.

TINKER, M. A. (1942): Individual and sex differences in speed of saccadic eye movements. In: J. F. Dashiell, Studies in personality 271-281. Mc. Graw Hill.

TITCHENER, E. B. (1910): A textbook of psychology. Mac Millan Co. pag. 265-302.

VERNON, M. D. (1952): A further study of visual perception. Cambridge University Press.

WELFORD, A. T. (1952): The "Psychological refractory period" and the timing of *high speed performance – a review and a theory. Br. J. psychol. 43; 2-19.*

WELFORD, A. T. (1959): Evidence of a single channel decision mechanism, limiting performance in a serial reaction task. Quart. J. exp. psychol. 11; 193-210.

WELFORD, A. T. (1960): The measurement of sensory-motor performance: survey and reappraisal of twelve years' progress. Ergonomics 3; 189-230.

WELLS. F. L., KELLY, M. *and* MURPHY, G. (1921): On attention and simple reactions. J. exp. psychol. 4; 391-398.

WHITE, C. T. *and* FORD, A. (1960): Eye movements during simulated radar search. J. opt. Soc. Amer. 50; 909-913.

WHITE, C. T. *and* FORD, A. (1959): Ocular activity in visual search. In: Visual search techniques. Ailene Morris and E. Porter Horne. (Ed) 124-133. Nat. Res. Council Publ. 712.

WHITE, C. T., EASON, R. G. *and* BARTLETT, N. R. (1962); Latency and duration of eye movements in the horizontal plane. J. Opt. Soc. Amer. 52; 210-213.

WILKINSON, R. T. (1958): The effect of sleep loss on performance. A.P.R.U., rep. no. 323.

WIRTH, W. (1907): Die Klarheitsgrade der Regionen des Sehfeldes bei verschiedenen Verteilungen der Aufmerksamkeit. Psych. Stud. 2; 30-89.

WOODROW, H. (1936): The measurement of difficulty. Psych. Rev. 43; 341-365.

WOODROW, H. (1938): The effect of pattern upon simultaneous letter span. Amer. J. psychol. 51; 83-96.

WOODWORTH, R. S. *and* SCHLOSBERG, H. (1954): Experimental psychology. Menthuen & Co.

WOODWORTH, R. S. *and* WELLS, F. L. (1911): Association tests. Psychol. Monogr. 57.

WUNDT, W. (1896): Grundrisz der Psychologie, Leipzig. page 239.

WUNDT, W. (1911): Physiologische Psychologie. Band III Leipzig.